# Visibility Check Based Operation Planning of Axisymmetric Components

by

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# Visibility Check Based Operation Planning of Axisymmetric Components

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# CERTIFICATE

It is to certify that the work contained in this thesis entitled "**Visibility Check Based Operation Planning of Axisymmtric Components** " by **Nilesh Kumar Jain**, has been carried out under my supervision and that this work has not been submitted elsewhere for the award of a degree.

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May, 1995

# ABSTRACT

The present work is directed towards operational sequence planning in Computer Aided Manufacturing (CAM), and to minimize the reliance of features in process planning. It uses the visibility status of a surface for determining if the surface can be machined from a given direction and subsequently uses the results of the visibility check for identification and sequencing of the machining operations. The advantages of visibility based approach are greater flexibility and less dependence on subjective aspects in process planning. A set of heuristics have been developed for machining operations sequencing for axisymmetric components. This work attempts to meet the machining operation nomenclature and sequencing standards of a specific industry (TISCO Growth Shop, Jamshedpur). The system graphically simulates the results of input pre-processing and visibility check, while, the results of machining oprations identification and sequencing are written in a file in the form of standard route card, as used in actual job shop. The entire source code for the system has been written in Turbo C programming langauge and has been implemented on IBM compatible PC-XT/AT.

# Dedicated to my Parents

# ACKNOWLEDGEMENTS

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**Nilesh Kumar Jain**

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# Chapter 1

# Introduction

## 1.1 Process Planning

Process Planning (PP), an important intermediate stage between design and manufacture of the product, is the systematic determination of the methods and means to manufacture a product economically and competitively. It *translates* the design representation into a sequence of ordered operations required to manufacture a product and *identifies* resources such as Material, Machines, Tools, Fixtures, etc. for these operations. The task of Process Planning involves selection, calculation and documentation. *Selection* of appropriate Processes, Machines, Operations and Sequence of operations according to batch size and accuracy of the parts. *Calculation* regarding Material, Tool life, Cutting speed, Feed, Depth of cut, Stock removal, Machining time and Machining cost. At last *Documentation* of Route Card or Process Planning sheet, Tool Instruction sheet and NC-part program [6,16].

### 1.1.1 Process Planning Levels

The task of process planning is carried out at the following three levels of detail in the top-down hierarchy [6] :

- Level 1. Operation Planning : Manufacturing processes identification and their sequencing to generate route cards,

- Level 2. Preliminary process planning : Resources selection to generate operation sheets,
- Level 3. Detailed process planning : Process parameters calculation to generate instruction sheets.

Figure 1.1(a) and Figure 1.1(b) show the Rotational Sweep Sections [1] for the Finished Part (FPSS) and Raw Stock (RSSS) (refer Section 2.1) respectively of an example part (known as Half Casing of a Gear Coupling), while Table 1.1 shows the how the route card would be prepared manually for the same example part listing the sequenced machining operations.

In the operation sheets further information regarding machines, cutting tools, fixtures, etc. are also specified. Finally, the instruction sheet will specify detailed process paremeters for individual operations.

A number of commercial packages such as **CAPSturn, CAPSmill**, etc. are available for the PP of level 3 and partially for the level 1 and level 2. The Operation Planning (level 1) is often not given due consideration in the commercial packages or is not flexible enough to suit the needs of the client's organization. In the present work we focus on Operation Planning (level 1) i.e. machining operations identification and their sequecing for axisymmetric components to be manufactured through turning operations and generating the route cards as per the TGS, Jamshedpur nomenclature and standards. Axisymmetric or symmetrical rotational components belong to a group of relatively important and frequently used parts such as Shafts, Spindles, Gear blanks, Wheel blanks, Gear coupling components, etc.

## 1.2 Need of CAPP

Conventional manual process planning frequently reflects a commitment to personal experience, preferences, or even prejudice of the particular planner. If different process planners are asked to develop a process plan for the same part, they would probably

[1] A Rotational Sweep Section is a 2D contour which, when rotated about the axis of rotation, results in the surface of axisymmetric part.

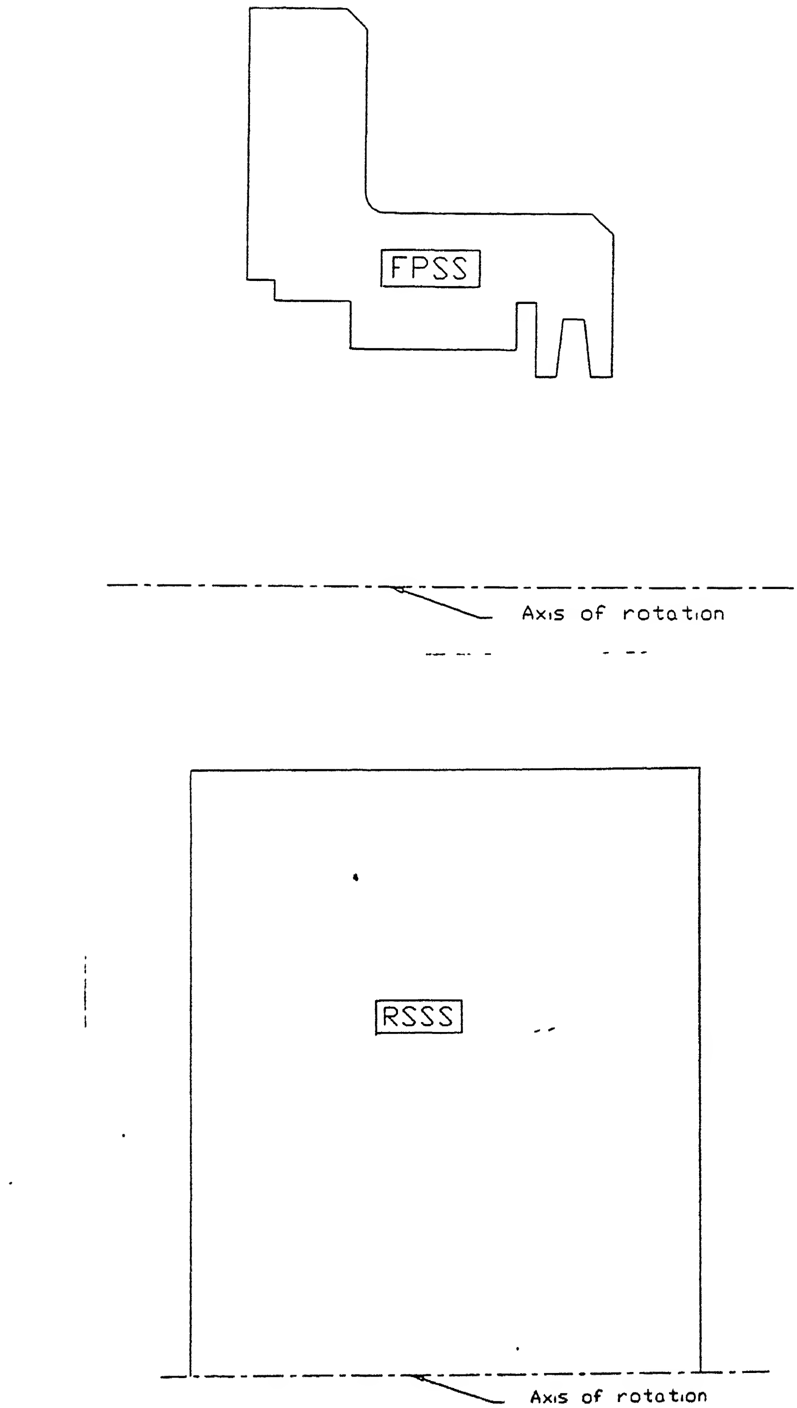


Figure 1.1: FPSS and RSSS of the example part (Half Casing).

Table 1.1: How route card would be prepared for the example part (Half Casing), courtsey TGS, Jamshedpur.

| Opn | Description of operation |
|---|---|
| 10. | — |
| 20. | Rough Machining :<br>Face; Drill and Bore; Turn O.D;<br>Step Turn; Shoulder Face; Remove Sharp Corners.<br>Reverse;<br>Face to Length; Turn O.D. Complete;<br>Remove Sharp Corners. |
| 30. | — |
| 40. | Finish Machining :<br>Face; Bore; Form V-groove; Turn O.D.; Step Turn; Shoulder Face; Remove Sharp Corners.<br>Reverse :<br>Face to Length; Counter Bores;<br>Form SQ-Groove; Turn O.D. Complete;<br>Remove Sharp Corners. |
| 50. | — |

come up with different plans and there is no guarantee that any one of them will constitute the optimum method for the manufacture of the part. What may even be more disturbing is that a process plan developed for a part during the current manufacturing program may be quite different from the old plan and it may never be used again. This causes wastage of effort and many inconsistencies in Routing, Tooling, Labour requirements, Costing and purchasing requirements.

Of course, process planning should necessarily not remain static. The current process planning practices should reflect the changes in batch sizes, availability of new technology, equipment, processes and tools, thus leading to an effective way of manufacturing a product. Unfortunately, due to the lack of uniformity among the manually prepared process plans, they do not reflect a consistent view towards changes in manufacturing technologies and processes.

Computer Aided Process Planning (CAPP) attempts to select an optimum manufacturing process and prescribe full details involved, without relying on a planner's individual experiences or preferences. CAPP is located at the the crossroads of information between engineering design and shop floor. CAPP bridges the Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM), thus playing a key role in developing the Computer Integrated Manufacturing Systems (CIMS) and Flexible Manufacturing System (FMS) [16]. In the advanced economies CAPP is seen as key element of CIMS, where a highly automated system will take over from CAD output and generate machine programs with minimal human assistance. In $3^{rd}$ world however, the role of CAPP as an automation tool is limited by the high cost of capital and labour. Even in labour-intensive markets like India, CAPP is important in maintaining quality and consistency of the output. Also CAD in India is still drafting, not much solid modelling.

### 1.2.1 Full Automation or Intelligent Assistance

As an alternative to the systems that perform in *"fully auotmated"* mode, most systems today are moving towards being a good *"assistant"* rather than good automatic systems. If we view the difficulties in CAPP systems, they are largely related to the

inability of the system, with information on only a limited part of the system, to solve a global problem in a robust manner. For example, Job-holding, Fixture and Tooling information may not be available as a solid model to be fed to the system, which produces a decision based on its available information. However, since this information is likely to be incomplete the choices are often suboptimal. Therefore the emphasis here is on the interface which allows the user to edit the decisions of the system, rather than on producing "optimal" decisions at all cost. This results in very significant savings in time, since only a few decisions need to be altered. At the same time, it avoids the occasionally extreme costs due to wrong decisions by the "fully automated" system. So, we may try to develop an **assistant** with the following characteristics [16] :

- It should help the user to save time by organizing the choices in a systematic manner,
- It should be user oriented rather than computer oriented,
- The user should always be able to override any decision made by the system,

## 1.3 CAPP Approaches

There are two traditionally recognized approaches to CAPP , the *variant* aprroach and the *generative* approach. However, with the rapid development of techniques, most of the CAPP systems do not fit exacly into any one of these and use the potentials of both the approaches thus leading to the *hybrid or semi-generative* approach. These CAPP approaches are implemented through *bottom-up* or *backward planning*, *top-down* or *forward planning* or *AI techniques*. The bottom-up or backward planning traces the task of PP from the finished part to the raw material and is oriented towards the variant approach of CAPP. Top-down or forward planning traces the task of PP from the raw material to the finished part and is oriented towards the generative approach of CAPP. While, the Knowledge Based Expert Systems (KBES) use the Artificial Intelligence (AI) techniques to handle a given class of objects whose features can be described using a set of predicates [1].

Most of the CAPP systems such as XPLANE [3], ICAPP [4], Micro-CAPP [5], PRICAPP[10], AIMSI [14] and those by Mazumdar [8] and Meeran [9] are feature oriented i.e. they are based on the automatic extraction or recognition of the machining attributes or features from the input data geometry. In automatic feature recognition, the system checks a specified set of elements against some rules or heuristics [9].

Features have been defined differently from time to time and there is no consensus on the defintion of a feature. A feature represents a collection of entities in an intelligent form that matches the way engineers think and hence provide information at higher conceptual level than a purely geometrical representation like lines, arcs and texts [8]. Another definition of the features defines them as the regions of machined parts having significance for Design, Process Planning and other related activities. A *manufacturing feature* can be defined as a portion of the part created by removing the material and using the same setup and tools during the machining [6]. Figure 1.2 shows some manufacturing features on the previously considered example part i.e. Half Casing.

There are some shortcomings of feature based CAPP. Basically it is a notion that human beings are very comfortable with features but machines are not Following are some aspects comparing the feature oriented CAPP with featureless CAPP based on visibilty checking :

### 1.3.1 Feature based versus Featureless CAPP

1. Feature nomenclatures are depedent on the type of industry, type of section in a particular industry, type of manufacturing process, etc., and these dependencies give rise to inconsistencies and non-uniformities in feature nomenclatures. In many cases design and manufacturing features will differ since the designer's features are concerned with functionality e.g. mating surfaces, whereas manufacturing features are concerned with the determination of appropriate manufacturing operations in process planning e.g. machining volumes [9]. Also, some non-standard features are commonly used in certain industries such as the "J-bevel" in TGS, Jamshedpur (refer Figure 3.6) and these features are specific only

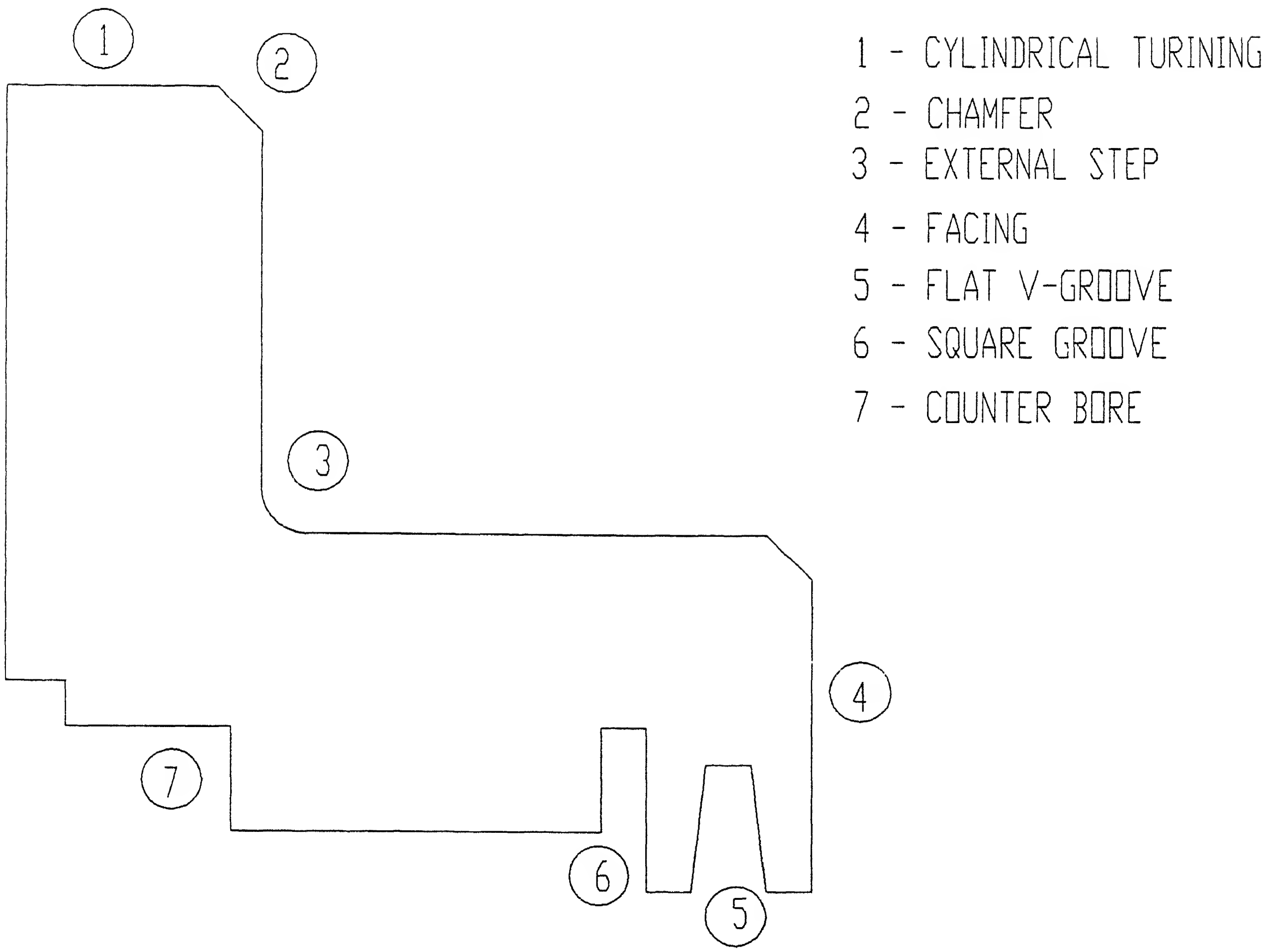


Figure 1.2: Some manufacturing features on the Example part (Half Casing of a Gear Coupling).

to that particular industry.

2. Feature based approach has no robust heuristic to solve the work piece holding problem globally, while the maximum visibility criterion adopted here (refer Section 3.2.1) can provide some guidelines for this.

3. Feature based approach cannot indicate the possibility of machining a particular surface from any given particular direction of machining while featureless approach uses visibility checking for the same.

4. Feature based CAPP requires the user to be an expert in manufacturing knowledge to input the data to the CAPP system and this defeats the very purpose of establishing a CAPP.

5. Feature based approach cannot recognize qualitatively *non-linear* surfaces e.g. arcs, special curves. Also it cannot distinguish between concave and convex arcs.

At the same time engineers find it easy to relate descritions using features. That is why after the sequencing decisions based on visibility, it may be useful to provide the user feedback in the language of the features.

## 1.4 Present Work

In the present work we adopted a *featureless approach* to the operation planning of axisymmetric components through *visibility checking* (refer Section 2.3) of various surfaces from different machining directions and providing the user feedback in the langauge of features for the ease of interpretation. Algorithm for visibility check from the direction of machining and the heuristics for the identification and the sequencing of machining operations for the *visible surfaces* have been developed for the same. The final output, which in this case involves human readable Route Cards, uses features but we note that the operation sequencing is based on the geometric notion of visibility and that these features are identified later.

### 1.4.1 Overall View of the Developed System

Figure 1.3 presents the information flow in the developed system, named as CARGAC (Computer Aided Route card Generation for Axisymmetric Components).

The Input Module of the developed system takes the DXF (Data Interchange File) files of AutoCAD drawings of Sweep Sections [2] of Raw Stock (RSSS), Intermediate Blank (IBSS) and Finished Part (FPSS) for the component with an intermediate manufacturing stage and that of only Raw Stock and Finished Part for the component without intermediate manufacturing stage as input, thus integrating the front end of the system with CAD. These DXF files can be generated by the user or may be inferred from 3D-CAD models. Since the current system does not assume the existence of 3D-CAD models, these DXF files are generated through the use of AutoCAD for drawing the different Sweep Sections. Different Sweep Sections are generated by referring to the corresponding engineering drawing. Since the current system makes no attempt to handle the scaling and dimensioning of the engineering drawings, these Sweep Section should be drawn to scale with reference to the lower left corner of the drawing as the origin (0, 0). The Input Module pre-processes the these DXF files and extracts the geometric information subsequently useful. It gives connected entities list of closed polyarc of IBSS or FPSS, as the case may be, as output and graphically simulates the superimposition of different sweep sections used as input to this module.

The Visibility Check Module of the system uses the output of input module as input and generates the lists of surfaces visible or accessible from different directions of tool access or visibility (refer Section 2.1) and simulates these results graphically.

The Sequencing Module identifies and sequences the Rough machining operations from visible surfaces lists of IBSS and Finsih machining operations from the visible surfaces list of FPSS.

Finally, the Output Module writes these operations list(s) in the a route card. The format of this route card specific to TGS, Jamshedpur.

[2] A Sweep Section is a 2D contour which, when rotated about the axis of rotation, results in the surface of axisymmetric part.

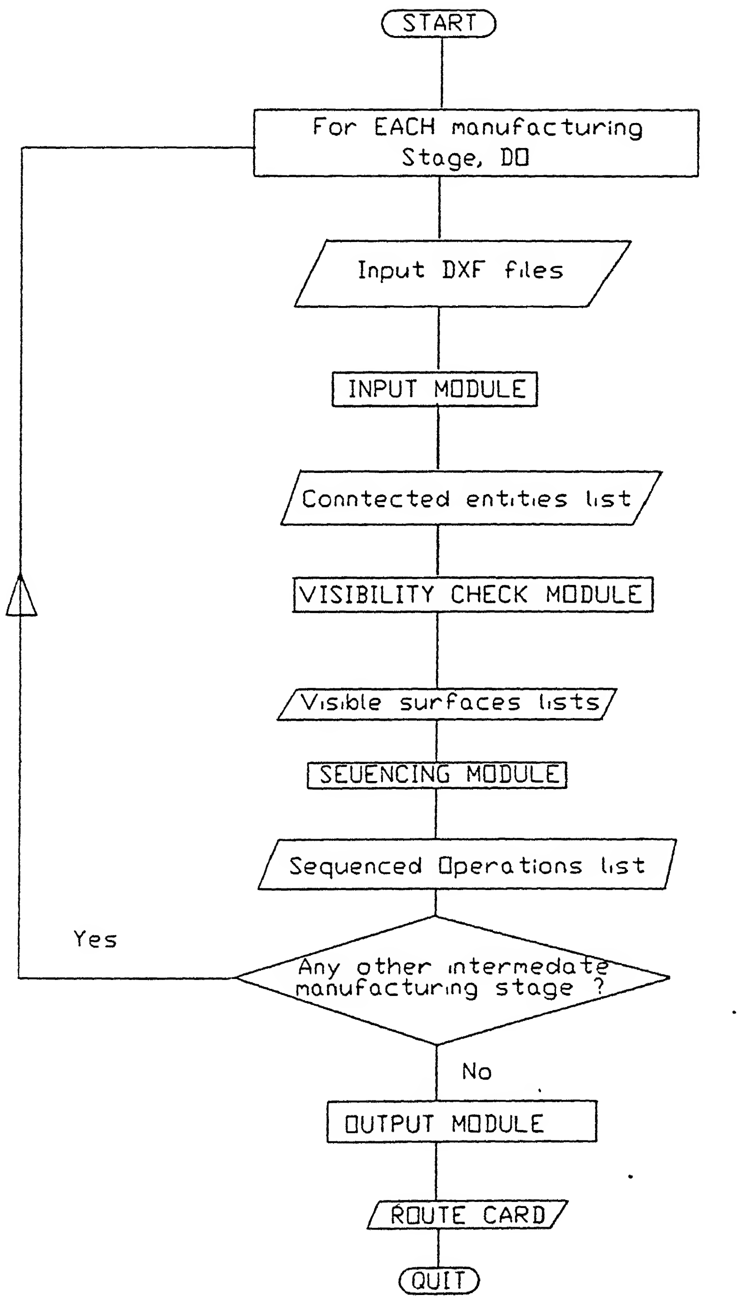


Figure 1.3: Information flow in the developed system (CARGAC : Computer Assisted Route Card Generation for Axisymmetric Components).

## 1.5 Organization of Dissertation

This dissertation is organized as follows :

**Chapter 2** discusses definitions, properties, the algorithm, and results of visibility checking.

**Chapter 3** describes heuristics and results of the machining operations identification and their sequencing.

**Chapter 4** describes the input and output interfaces of the developed system and presents more results of visibility checking.

**Chapter 5** concludes with the scope of future work.

# Chapter 2

# Visibility Checking

The notion of the visibility check is that a given surface can only be machined from a particular direction of machining, if the tool can access and approach along the surface from that direction. The whole surface can be machined from a direction, if the entire surface is visible or can be accessed from that direction. *Visibility check* determines whether or not a surface is visible from a particular direction and consequently lists the possible directions from which a surface can be accessed for machining purposes. It decomposes the sweep section polyarc into the lists of surfaces visible or accessible from the different visibility directions using the geometric information of Sweep Section polyarc entities, which may be an arc or an edge. If a surface is visible or can be accessed from more than one direction, then it will appear in more than one list.

## 2.1 Definitions

1. **Boundary of an object :** Boundary of an object $\sigma$ is the set of all points in $\sigma$ for which any $\epsilon$ neighbourhood (disk of radius $\epsilon$ about that point) contains some points outside the object. It is denoted as $\delta\sigma$.

2. **Interior of an object :** Interior of an object $\sigma$ is the set of all points for which there exists an $\epsilon$-neighbourhood completely inside the object. It is denoted by $\text{int}(\sigma)$.

3. **Sweep Section (SS) :** Sweep section for an axisymmetric component is the closed single chain or simple polyarc (a closed polyarc without any hole) consisting of edges and arcs, the sweeping of which about the axis of rotation generates the volume of the component. Sweep Sections corresponding to Raw Stock, Intermediate Blank and Finished Part are denoted as RSSS, IBSS, FPSS respectively.

4. **Machining Volume(MV) :** This is the Boolean diffenrence between two Sweep Sections polyarcs. Figure 2.1 shows RSSS, IBSS, FPSS and Rough MV as the Boolean difference between RSSS and IBSS polyarcs while Finish MV as the Boolean difference between IBSS and FPSS polyarcs.

5. **Visibility Angle or Tool Access Direction :** It is the angle made by the tool tip with 3 o'clock towards the East as reference direction and measured in counter-clockwise direction. Following Tool Access Directions and corresponding Visibility angles are commonly used for Turning operations :

   - Axially forward or LEFT direction : Visibility angle = $0^o$
   - Radially outward or AXIS direction : Visibility angle = $90^o$
   - Axially backward or RIGHT direction : Visibility angle = $180^o$
   - Radially inward or OUTSIDE direction : Visibility angle = $270^o$

   Figure 2.2 shows some tool access directions and corresponding visibility angles. Point $P_1$ is visible from $180^o$, $225^o$ and $270^o$ whereas the point $P_2$ is visible from $90^o$. While, $P_3$ is visible from both $0^o$ and $90^o$, the edge containing it is only partially visible from $0^o$.

6. **External Point :** A point in the visibility direction and located *outside* the sweep section polyarc.

7. **Point Membership Classification (PMC) :** To determine if any point in space is *INside*, *OUTside*, or *ON* the boundary of any solid [12].

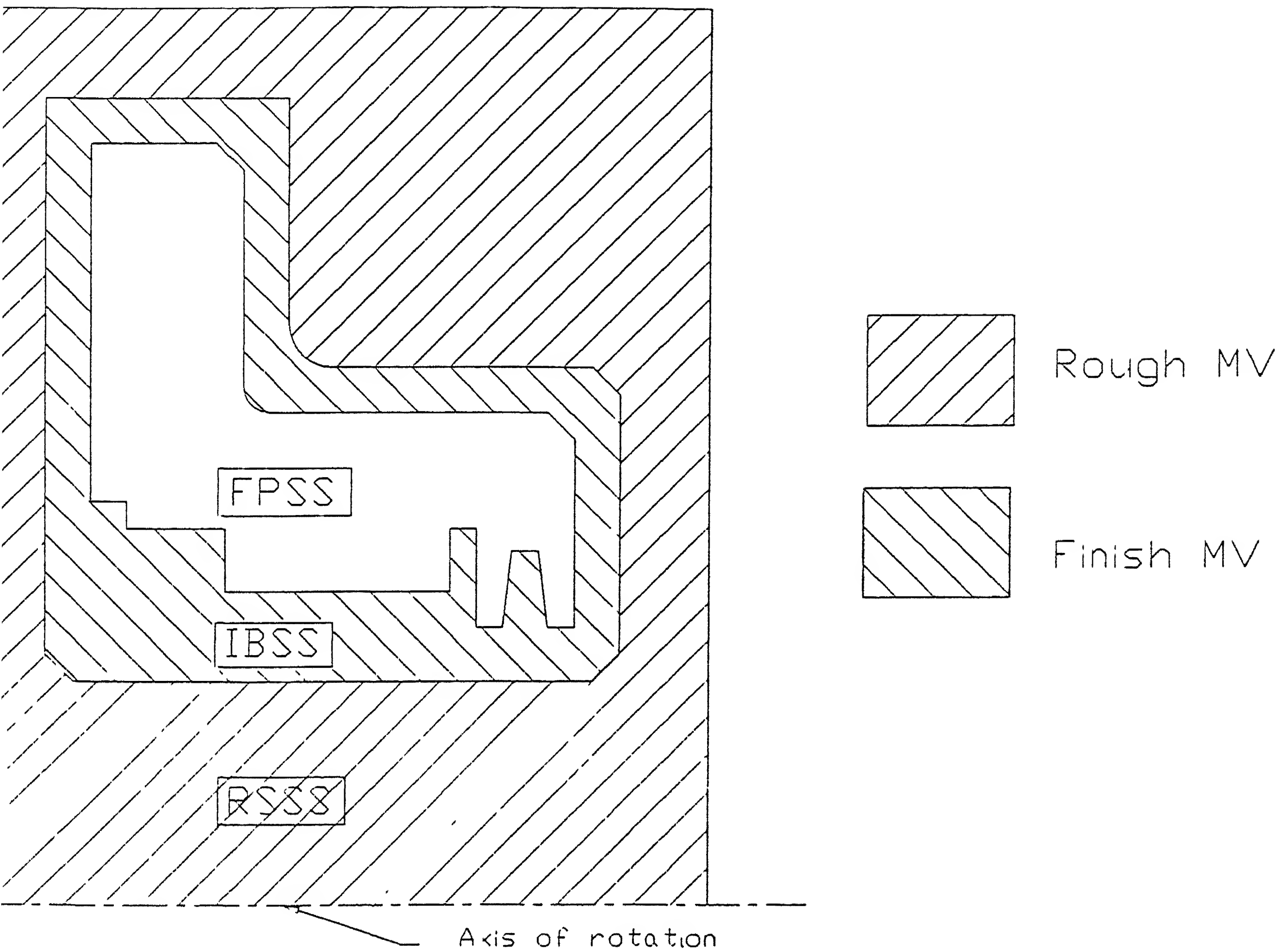


Figure 2.1: Different Sweep Sections and Machining Volumes.

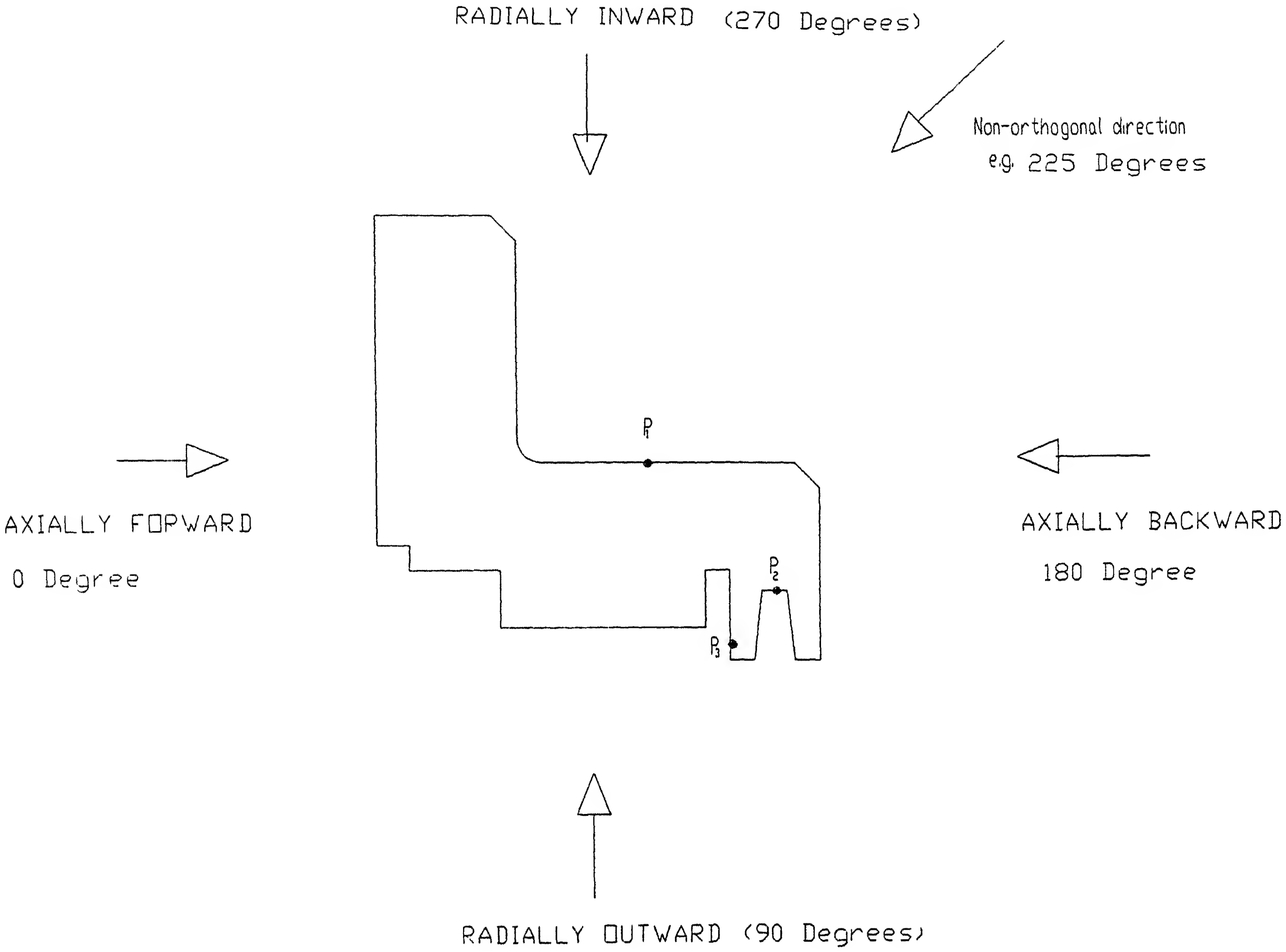


Figure 2.2: Different tool access directions and associated visibility angles.

8. **Line Membership Classification (LMC) :** To segment a given line with reference to a closed contour into three subsets as IN, ON and OUT corresponding to portions of the candidate line which lie respectively in the *interior*, *boundary* and *complement* of the closed contour. LMC status of a line is IN if any part of it is lies in the *interior* of the contour, else ON if any part of it is on the *boundary* of the contour else OUT.

9. **Point Visibility :** A point P on the sweep section boundary S is visible from an External Point D if and only if, Boolean intersection of the line PD with int(S) is a null set, e,g. No part of the line PD is 'IN' the S or LMC status of the line PD with sweep section polyarc is NOT equal to 'IN' [12].

10. **Lines of Projection :** Projections of two ends $V_1$ and $V_2$ of an edge E in the *opposite direction* of the visibility and outside the sweep section polyarc are referred as Lines of Projections of the edge and are denoted as $Proj_1$ and $Proj_2$.

11. **Region of Projection (Π) :** It is the region bounded by the edge E, the two lines of projection $Proj_1$ and $Proj_2$ and an external boundary Ext. It is denoted as $\Pi(E, \theta)$.

12. **Edge Visibility :** An edge E with two ends $V_1$ and $V_2$ is *fully visible* from a direction $\theta$ if all the points on this edge are point visible from that direction. It has been proved through the Visibility theorem that this happens only when no portions of the Lines of Projections, $Proj_1$ and $Proj_2$, is 'IN' the sweep section polyarc or LMC status of $Proj_1$ and $Proj_2$ with sweep section polyarc are not equal to 'IN'. This means that $\Pi(E, \theta) \cap \text{int(SS)} = \emptyset$.

13. **Partial Edge Visibility :** An Edge E with two ends $V_1$ and $V_2$ is *partially visible* from a direction $\theta$ if, some points on the edge are not point visible.

    Figure 2.3(a) and Figure 2.3(b) illustrate the example of Partial Edge Visibility.

14. **Tangency Number of an arc :** It is the number of tangents which can be drawn to the arc from the visibility direction $\theta$.

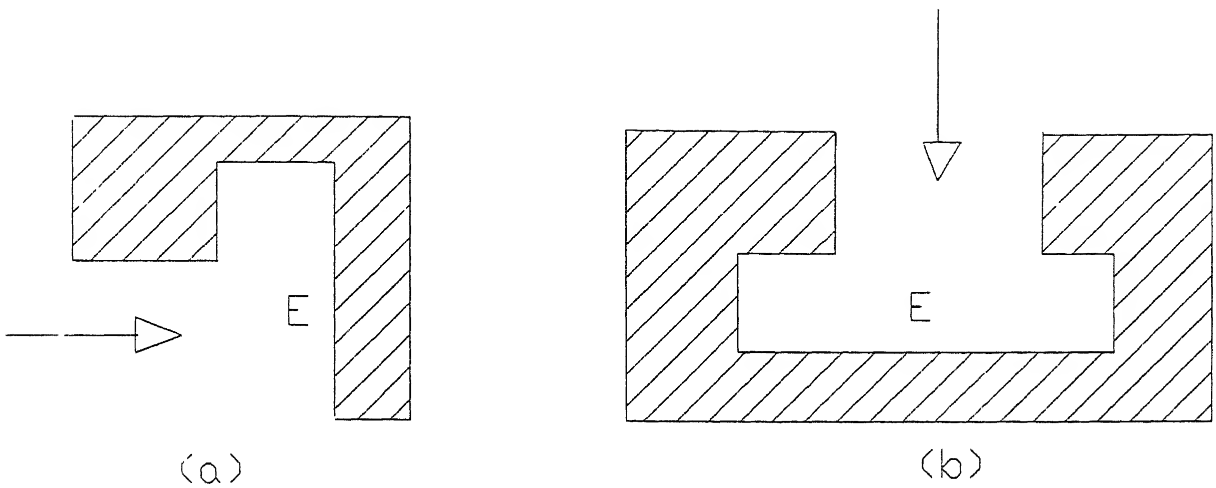


Figure 2 3: Examples of Partial Egde Visibility. Only a part of the edge E is visible in each case.

Let $\phi_r$ and $\phi_l$ be the perpendicular directions to the right side and left side of the visibility direction $\theta$ repectively, and let $\theta_s$ and $\theta_e$ be the start angle and end angle of the arc. There can be three possible cases as follows :

- Double Tangency Case : If *BOTH* $\phi_r$ and $\phi_l$ are within $\theta_s$ and $\theta_e$ , (Figure 2.4a.)
- Single Tangency Case : If *ANYONE* of $\phi_r$ and $\phi_l$ is within $\theta_s$ and $\theta_e$ , (Figure 2.4b.)
- No Tangency Case : If *NONE* of $\phi_r$ and $\phi_l$ is within $\theta_s$ and $\theta_e$ , (Figure 2.4c.)

**15. Arc Visibility :** An arc A with two ends $V_1$ and $V_2$ is *fully visible* from a direction $\theta$ if all points on the arc are point visible from direction $\theta$. This can occur only if it has no tangency point in the $\theta$ direction.

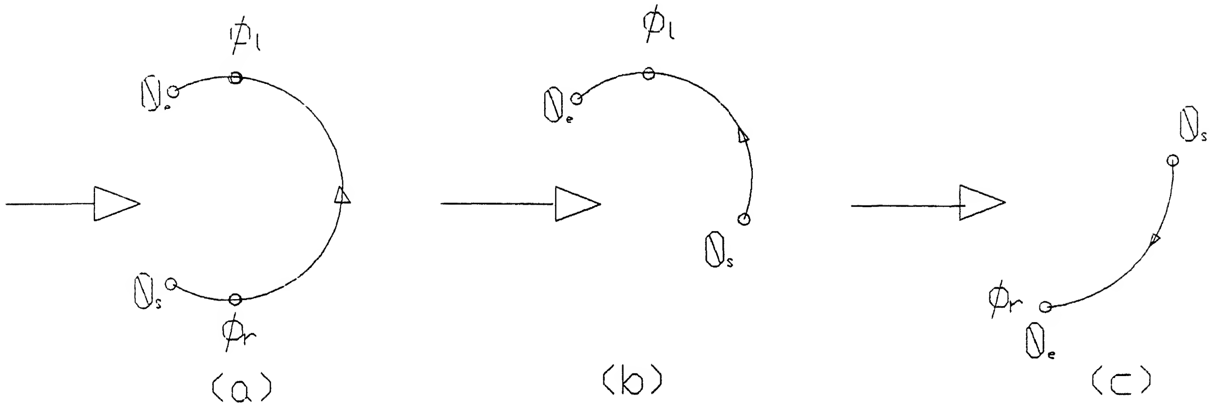


Figure 2.4: Possible tangency cases of an arc from visibility direction. (a) Double tangency case, (b) Single tangency case, (c) No tangency case.

## 2.2 Visibility Theorem

**Theorem :** *If two end points $V_1$ and $V_2$ of an* **edge** *$E_j$ are visible from a direction $\theta_i$ then the whole edge is visible from that direction.*

**Proof :** Let the edge $E_j$ be on the boundary of a single connected object $\sigma$ , $Proj_1$ and $Proj_2$ are the Lines of projection of the ends $V_1$ and $V_2$, $Ext_j$ is the projection of the edge $E_j$ in the direction $\theta_i$ and let $\Pi$ be the region of projection.

Let us assume that the edge $E_j$ is NOT visible from $\theta_i$ direction i.e. $\Pi \cap \mathrm{int}(\sigma) \neq \emptyset$. Consider a point $P_1$ such that $P_1 \in \Pi \cap \mathrm{int}(\sigma)$ i.e. $P_1 \in \mathrm{int}(\sigma)$ and consider another point $P_2 \in \sigma$ such that $P_2$ NOT $\in \Pi$. Since $\sigma$ is singly connected there must be a path entirely inside $\sigma$ from the point $P_1$ to $P_2$ such that it crosses the the boudary of $\Pi$ at least once at some point $P_j$. This path cannot cross $\Pi$ at $Ext_j$ since $Ext_j$ is not in $\sigma$. The path cannot cross $\Pi$ at $E_j$ also, since the edge $E_j$ is a single entity on the boundary of $\sigma$ and cannot have points of $\sigma$ on both sides of it. If this path crosses the line of projection $Proj_1$, then $Proj_1 \neq$ OUT of interior of $\sigma$ and similarly for $Proj_2$. Hence, if the the edge $E_j$ is NOT visible, at least one Line of Projection $Proj_1$ or

$Proj_2$ is IN the int($\sigma$).

**Corollary :** *Any curve with two endpoints $V_1$ and $V_2$ and with no tangency case in the visibility direction $\theta_i$ will be visible from that direction if both its endpoints are visible from the $\theta_i$ direction.*

In the next Section we present the algorithm for testing visibility of the boundary entities on Sweep Section $\sigma$.

## 2.3 Visibility Check Algorithm

Let $\theta_i$ be the visibility angle,

where i varies from one to four conventional visibility directions plus number of auxiliary visibility directions.

and let $E_j$ be an entity of a polyarc sweep section with ends $V_1$ and $V_2$,

where $E_j \in$ S.

for each visibility direction $\theta_i$

for each entity $E_j$

if $E_j$ is an **EDGE**,

if LMC of $Proj_1 \neq$ IN **AND** LMC of $Proj_2 \neq$ IN,

then entity $E_j$ is **VISIBLE** from $\theta_i$.

if $E_j$ is an **ARC**,

then find Tangency Points Number of the arc in $\theta_i$ direction.

if No Tangency Case,

then test the arc as an EDGE.

if Single Tangency Case,

then **BREAK** the arc into **TWO** arcs :

from start angle $\theta_s$ to **nearest** tangency point;

from **nearest** tangency point to end angle $\theta_e$ ;

test the broken arcs as the EDGES.

if Double Tangency Case,

then **BREAK** the arc into **THREE** arcs :

from start angle $\theta_s$ to **nearest** tangency point;
from **nearest** tangency point to second tangency point ;
from second tangency point to end angle $\theta_e$ ;
test the broken arcs as the EDGES.

endfor;

## 2.4 Correctness of the algorithm

The Table 2.1 summarizes the different visibility status of the edge $E_j$ corresponding to different possible combinations of LMC status of its Lines of Projection $Proj_1$ and $Proj_2$. By the visibility theorem, any edge whose both end points are visible is fully visible and Table 2.1 reflects only this.

Table 2.1: Possible LMC status of $Proj_1$ and $Proj_2$ of an edge $E_j$ and corresponding visibility status of the edge $E_j$.

| | $Proj_2$ | | |
|---|---|---|---|
| $Proj_1$ | OUT | ON | IN |
| OUT | FULLY visible | FULLY visible | NOT FULLY visible |
| ON | — | FULLY visible | NOT FULLY visible |
| IN | — | — | NOT FULLY visible |

The partially visible edge has some part near one or both end points invisible. These cases can be handled by flagging the partially visible edges and then breaking the partially visible edge into the visible and invisible edges at the breaking. For

the ARCS these cases can be detected through *Tangency Point Number* but, for LINEAR edges, the detection of the breaking point is computationally expensive. In the present work partial visible cases for the ARCS only have been handled.

## 2.5 Test Example

Figure 2.5 shows the FPSS polyarc of the Example 1 as input to the *visibility check* routine with circled numbers representing the entity serial number, while Figure 2.6(a), Figure 2.6(b), Figure 2.6(c) and Figure 2.6(d) illustrate the surfaces visible from different Tool Access Directions commonly used for Turning operations thus decomposing the FPSS polyarc through the visibility checking.

At the end of this process we have identified the visibility direction of entity in the sweep section. Subsequent integration with a CAM system would require extensive knowledge of tool and machine configuration, and is part of the Level 2 and Level 3 of Process Planning, and has not been discussed in the present work.

In the next chapter we identify the machining attributes and operations for the visible surfaces only and sequence those operations.

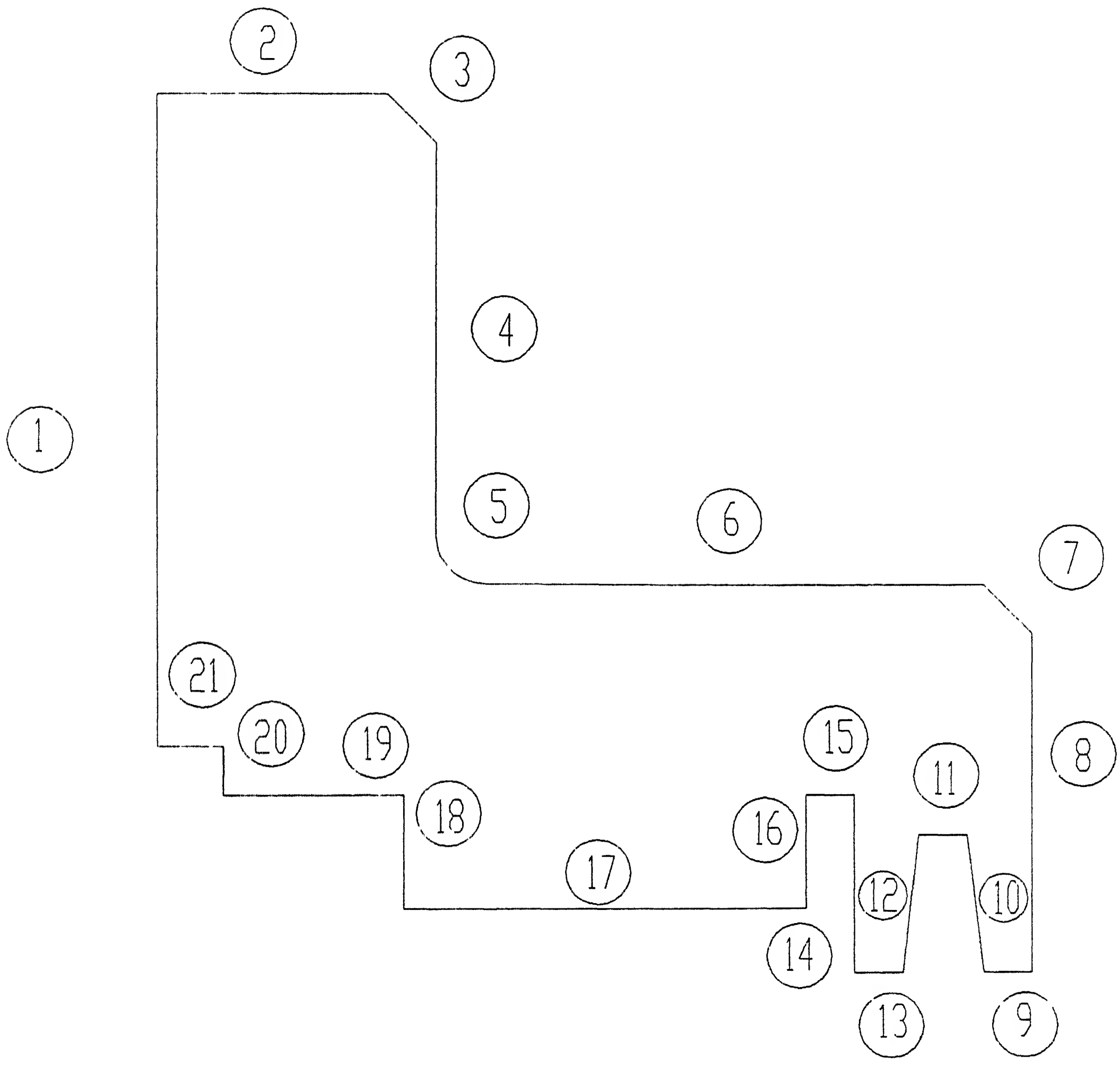


Figure 2.5: FPSS polyarc of Example 1 (Half Casing) as input to the visibility check.

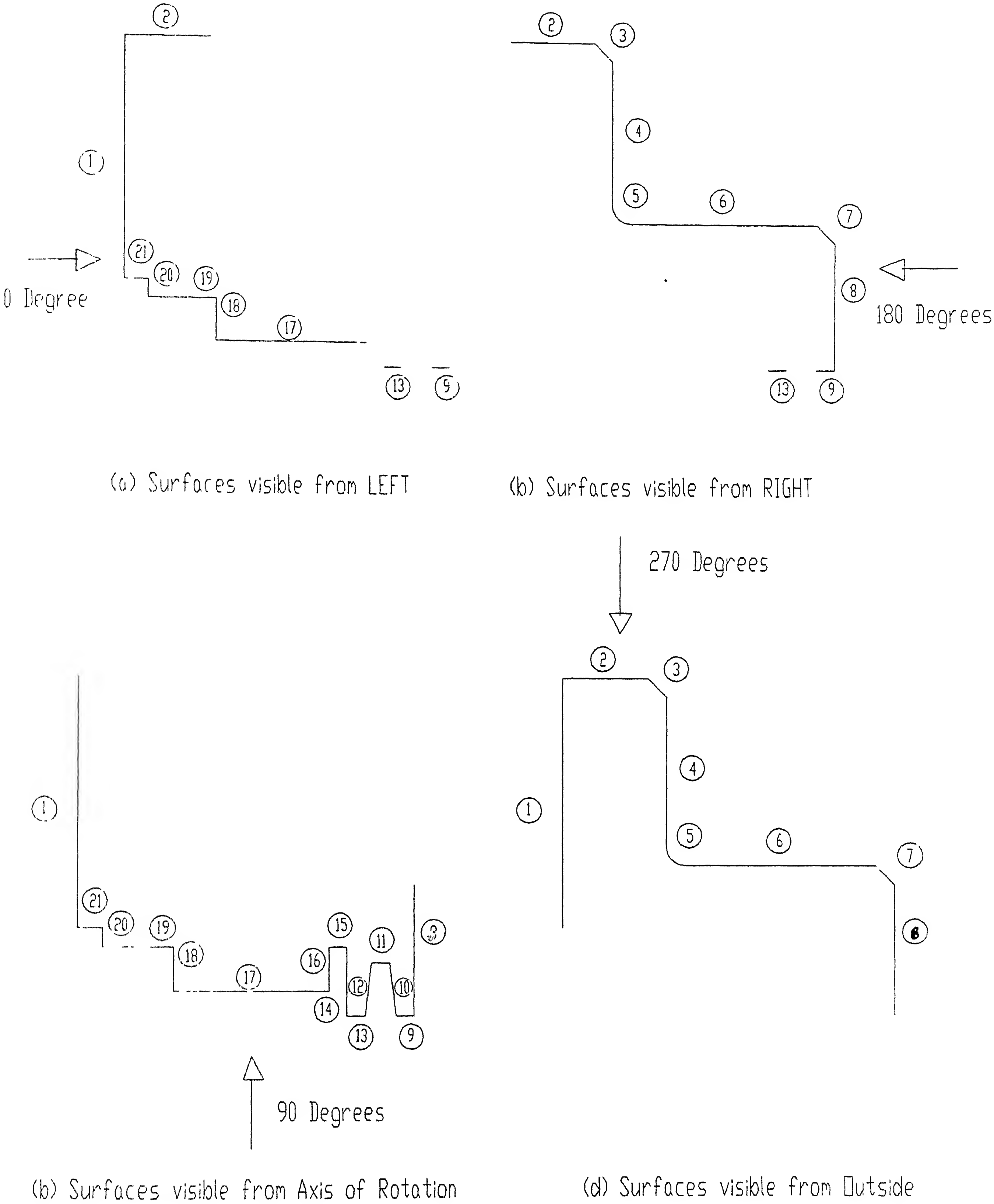


Figure 2.6: Results of visibility check for the Example 1 (Half Casing) from different directions.

# Chapter 3

# Operation Planning of Axisymmetric Components

The task of operation planning involves the identification of machining operations to manufacture an accessible surface or a group of accessible surfaces followed by the sequencing of the identified machining operation with the objective of minimizing the machining time and/or machining cost. As mentioned earlier, generation of an optimum or acceptable sequence requires detailed knowledge of the Machine tool, Cutting tool, Fixtures, etc. which are not available to the present system at this stage. As such, the sequence generated may be viewed as nominal. In practice, the list of operations generated by the system should be edited by the user. This will result in significant reduction in time while maintaining the final control with the user.

For the ease of human interpretation the results of visibility check are being attributed some simple or compound attribute or feature name and associated machining operations details through simple and compound identification of machining attributes or operations. The heuristics for the identification of these attributes or features, their nomenclature and associated machining operations details in the present work are as per the current manufacturing practices of TISCO Growth Shop, Jamshedpur. The objective of this exercise is to produce Route Cards that are sufficiently similar to existing practices. However these features or attributes play little role in the Computer Adided Manufacturing process itself, since direct Operation Planning can be carried out based on the entities being machined and relevant tool and machine tool

attributes.

## 3.1 Simple Identification of Operations

Simple attributes or features and associated machining operation details are identified through simple identification which involves only single entity at a time. These simple features include O.D / Cylindrical turning, Taper turning, Facing, Chamfering, Drilling, Boring, Taper boring for the linear surfaces and Machine radius, Give radius and Machine undercut for curved surfaces. Heuristics proposed and used in the present work for the identification of these simple attributes are being presented in the algorithmic form. [1]. We also note that for other organizations or other machining conditions, some of these heuristics may need to be modified, but the visibility conditions will remain unaltered.

### 3.1.1 Simple Identification heuristics

Let axis of rotation of SS polyarc be at $(X_{cen}, Y_{cen})$ and
let lower-left and top-right corners of Minimum Enclosing Rectangle of SS polyarc be at $(X_{min}, Y_{min})$ and $(X_{max}, Y_{max})$.
For each entity $E_j$ of SS polyarc with ends $V_1$ and $V_2$ at $(X_1,Y_1)$ and $(X_2,Y_2)$;
if $E_j$ is an ARC,
  if $Y_1 = Y_2$, AND the arc is concave,
    if $|X_2 - X_1| <$ UNDERCUT LIMIT, then MACHINE UNDERCUT.
    else MACHINE U-GROOVE.
  else $(Y_1 \neq Y_2)$
      if RADIUS of the ARC < RADIUS LIMIT, then GIVE RADIUS.
      else MACHINE RADIUS.
if $E_j$ is an EDGE,
  if $X_1 = X_2$ AND $Y_1 \neq Y_2$, then VERTICAL LINE.
    if $X_1 = X_2 = X_{min}$ or $X_{max}$, then FACE.

[1]We are grateful to Mr. L.K. Mahato of TGS, Jamshedpur for datailed discussions which have led to these heuristics

else if the EDGE is VISIBLE from Axis of Rotation ($90^o$),
then INTERNAL VERTICAL LINE.
else the EDGE is VISIBLE from outside ($270^o$),
then EXTERNAL VERTICAL LINE.
if $X_1 \neq X_2$ AND $Y_1 = Y_2$, then HORIZONTAL LINE.
if $Y_1 = Y_2 = Y_{cen}$, then AXIS of ROTATION (skip it from visibility check).
else if $Y_1 = Y_2 = Y_{min}$, then DRILL or BORE.
else if $Y_1 = Y_2 = Y_{max}$, then CYLINDRICAL or O.D.TURNING.
else if the EDGE is VISIBLE from Axis of Rotation ($90^o$),
then INTERNAL HORIZONTAL LINE.
else the EDGE is VISIBLE from outside ($270^o$),
then EXTERNAL HORIZONTAL LINE.
if $X_1 \neq X_2$ AND $Y_1 \neq Y_2$, then INCLINED LINE,
if $|X_2 - X_1| <$ CHAMFER LIMIT, then CHAMFER.
if CHAMFER LIMIT $< |X_2 - X_1|$ AND edge is NOT throughout the SS length,
if the EDGE is VISIBLE from Axis of Rotation ($90^o$),
then COUNRTER SINK.
if the EDGE is VISIBLE from outside ($270^o$),
then TAPER TURN.
if the edge is throughout the SS polyarc length,
if the EDGE is VISIBLE from Axis of Rotation ($90^o$),
then TAPER BORE.

## 3.2 Compound Identification of Operations

Compound attributes and their associated machining operations details are identified through compound identification which is based on the grouping together of simple attributes. These compound attributes pertain to some particular geometries and involve certain combinations of a group of entities according to some heuristics. These

compound attributes include Step Turn, Counter bore, Groove or Neck, different types of Recess i.e. Recess on Face, Recess on Bore, Recess on O.D. and J-bevel. The heuristics for the identification of these compound attributes have been developed to be independent of direction of traverse of the sweep section polyarc. In some cases such as Step Turn, these heuristics also sequence the machining operations partially. These heuristics are being presented in the subsequent subsections.

In the following, we traverse the entity list with using a connected triple of entities $E_j$, $E_{j+1}$ and $E_{j+2}$ with vertices $V_1$, $V_2$, $V_3$ and $V_4$ at ($X_1$,$Y_2$), ($X_2$,$Y_2$), ($X_3$,$Y_3$) and ($X_4$,$Y_4$) respectively.

### 3.2.1 GROOVE or NECK Identification

Figure 3.1(a) to Figure 3.1(f) represent the various Groove or Neck geometries corresponding to the following cases.

if $E_j$ and $E_{j+1}$ are INCLINED LINES.
  if $E_j$ and $E_{j+1}$ are visible from Axis of Rotation,
    if $Y_2 > Y_1$ AND $Y_2 > Y_3$,
      then MACHINE INTERNAL V-GROOVE. (see Figure 3.1(a).)
  if $E_j$ and $E_{j+1}$ are visible from Outside,
    if $Y_2 < Y_1$ AND $Y_2 < Y_3$,
      then MACHINE EXTERNAL V-GROOVE. (see Figure 3.1(b).)
if $E_j$ and $E_{j+2}$ are INCLINED LINES and are visible from $0^o$,
  and $E_{j+1}$ is INTERNAL HORIZONTAL LINE with
  its length < GROOVE WIDTH LIMIT,
  if $Y_1 < Y_2$ AND $Y_4 < Y_3$,
  then MACHINE INTERNAL FLAT V-GROOVE. (see Figure 3.1(c).)
  if $Y_1 > Y_2$ AND $Y_4 > Y_3$,
    then MACHINE EXTERNAL FLAT V-GROOVE. (see Figure 3.1(d).)
if $E_j$ and $E_{j+2}$ are INTERNAL VERTICAL LINES
  and $E_{j+1}$ is INTERNAL HORIZONTAL LINE with

its length < GROOVE WIDTH LIMIT,
if $Y_1 < Y_2$ AND $Y_4 < Y_3$,
then MACHINE INTERNAL SQUARE GROOVE. (see Figure 3.1(e).)
if $E_j$ and $E_{j+2}$ are EXTERNAL VERTICAL LINES
and $E_{j+1}$ is EXTERNAL HORIZONTAL LINE with
its length < GROOVE WIDTH LIMIT,
if $Y_1 > Y_2$ AND $Y_4 > Y_3$,
then MACHINE EXTERNAL SQUARE GROOVE. (see Figure 3.1(f).)

### 3.2.2 STEP Identification

The Step should be detected only after the Groove or Neck detection as some Step geometries are subsets of Grooves. Figure 3.2(a) to Figure 3.2(e) and Figure 3.3(f) to Figure 3.3(j) show the various possible Step geometries corresponding to Case (a) to Case (j) respectively and identified through following heuristics.

if $E_j$ is EXTERNAL VERTICAL LINE AND $E_{j+1}$ is ARC
AND $E_{j+2}$ is EXTERNAL HORIZONTAL LINE,
if $Y_1 > Y_4$,
then MACHINE STEP TURN and SHOULDER FACE.
(See Figure 3.2(a).)
else if $E_j$ is EXTERNAL VERTICAL LINE AND
$E_{j+1}$ is EXTERNAL HORIZONTAL LINE,
if $Y_1 > Y_3$,
then MACHINE STEP TURN and SHOULDER FACE.
(See Figure 3.2(b).)
else if $E_j$ is EXTERNAL VERTICAL LINE AND $E_{j+1}$ is ARC
AND $E_{j+2}$ is INCLINED LINE,
if ($Y_1 > Y_2$ AND $Y_2 > Y_3$ AND $Y_3 > Y_4$),
then MACHINE STEP TURN followed by TAPER TURN

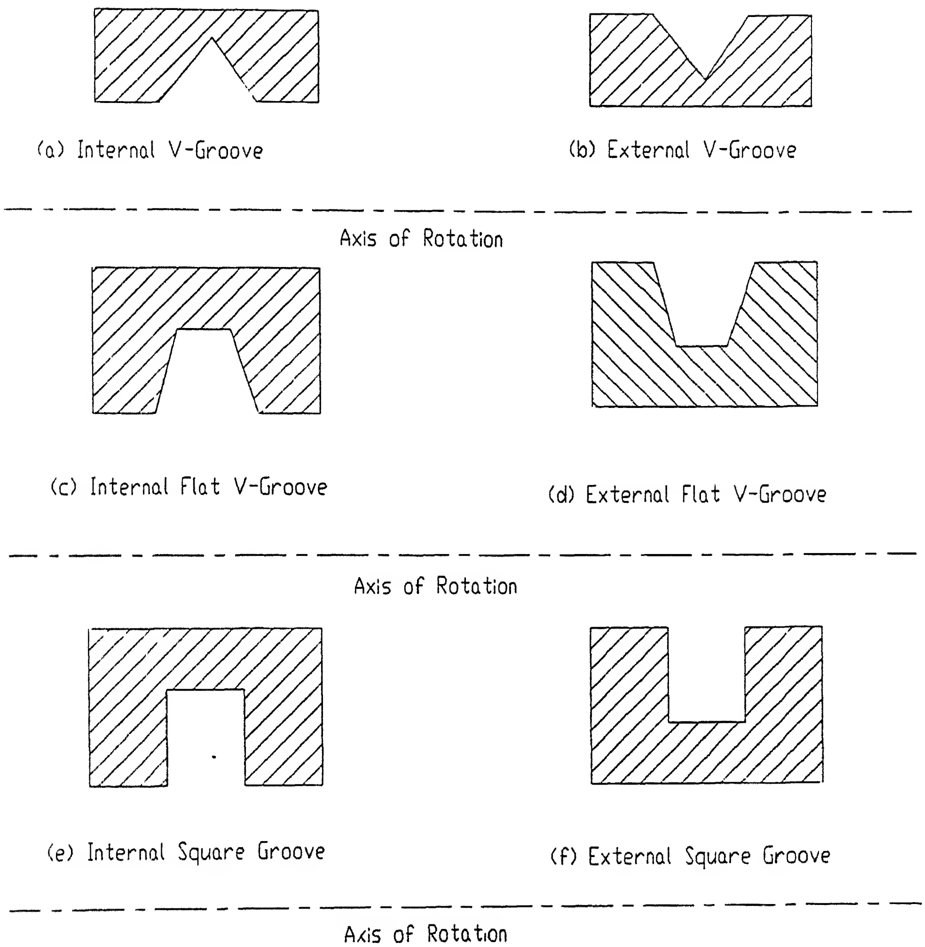


Figure 3.1: Different GROOVE or NECK geometries.

and SHOULDER FACE.

(See Figure 3.2(c).)

else if $E_j$ is EXTERNAL VERTICAL LINE AND $E_{j+1}$ is INCLINED LINE,

if ($Y_1 > Y_2$ AND $Y_2 > Y_3$),

then MACHINE STEP TURN and TAPER TURN.

(See Figure 3.3(d).)

else if $E_j$ and $E_{j+2}$ are INCLINED LINES AND $E_{j+1}$ is ARC,

if ($Y_1 > Y_2$ AND $Y_2 > Y_3$ AND $Y_3 > Y_4$),

OR ($Y_1 < Y_2$ AND $Y_2 < Y_3$ AND $Y_3 < Y_4$),

then MACHINE STEP TURN followed by two

TAPER TURNS and SHOULDER FACE.

(See Figure 3.2(e).)

else if $E_j$ and $E_{j+1}$ are INCLINED LINES,

if ($Y_1 > Y_2$ AND $Y_2 > Y_3$), OR ($Y_1 < Y_2$ AND $Y_2 < Y_3$),

then MACHINE STEP TURN and two TAPER TURNS.

(See Figure 3.3(f).)

else if $E_j$ is EXTERNAL HORIZONTAL LINE AND $E_{j+1}$ is ARC

AND $E_{j+2}$ is EXTERNAL VERTICAL LINE,

if $Y_1 < Y_4$,

then MACHINE STEP TURN followed by SHOULDER FACE.

(See Figure 3.3(g).)

else if $E_j$ is EXTERNAL HORIZONTAL LINE AND

$E_{j+1}$ is EXTERNAL VERTICAL LINE,

if $Y_1 < Y_3$,

then MACHINE STEP TURN and SHOULDER FACE.

(See Figure 3.3(h).)

else if $E_j$ is INCLINED LINE AND $E_{j+1}$ is ARC

AND $E_{j+2}$ is EXTERNAL VERTICAL LINE,

if $Y_1 < Y_2$ AND $Y_2 < Y_3$ AND $Y_3 < Y_4$,

then MACHINE STEP TURN followed TAPER TURN

and SHOULDER FACE.

(See Figure 3.3(i).)

else $E_j$ is INCLINED LINE AND $E_{j+1}$ is EXTERNAL VERTICAL LINE,

if $Y_1 < Y_2$ AND $Y_2 < Y_3$,

then MACHINE STEP TURN followed by TAPER TURN.

(See Figure 3.3(j).)

### 3.2.3 COUNTER BORE Identification

Figure 3.4(a) to Figure 3.4(d) show the various possible Counter Bore geometries corresponding to Case (a) to Case (d) respectively, identified through following heuristics.

if $E_j$ is INTERNAL HORIZONTAL LINE AND $E_{j+1}$ is ARC

AND $E_{j+2}$ is INTERNAL VERTICAL LINE,

if $Y_1 > Y_4$, then MACHINE COUNTER BORE. (See Figure 3.4(a).)

else if $E_j$ is INTERNAL HORIZONTAL LINE AND

$E_{j+1}$ is INTERNAL VERTICAL LINE,

if $Y_1 > Y_3$, then MACHINE COUNTER BORE. (See Figure 3.4(b).)

else if $E_j$ is INTERNAL VERTICAL LINE AND $E_{j+1}$ is ARC

AND $E_{j+2}$ is INTERNAL HORIZONTAL LINE,

if $Y_1 < Y_4$, then MACHINE COUNTER BORE. (See Figure 3.4(c).)

else $E_j$ is INTERNAL VERTICAL LINE AND

$E_{j+1}$ is INTERNAL HORIZONTAL LINE,

if $Y_1 > Y_3$, then MACHINE COUNTER BORE. (See Figure 3.4(d).)

### 3.2.4 RECESS Identification

Figure 3.5(a) shows the geometry of a Recess on Face, Figure 3.5(b) shows the geometry of a Recess on Bore, and Figure 3.5(c) depicts the Recess on O.D. geometry respectively.

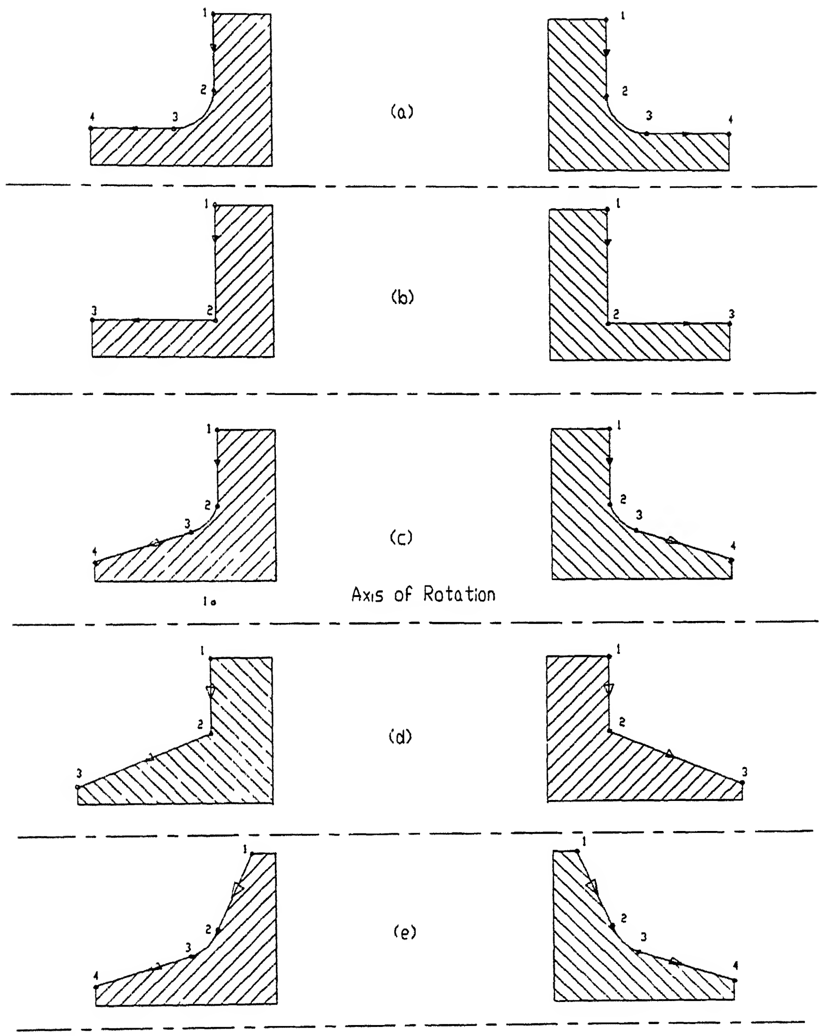


Figure 3.2: Different STEP geometries.

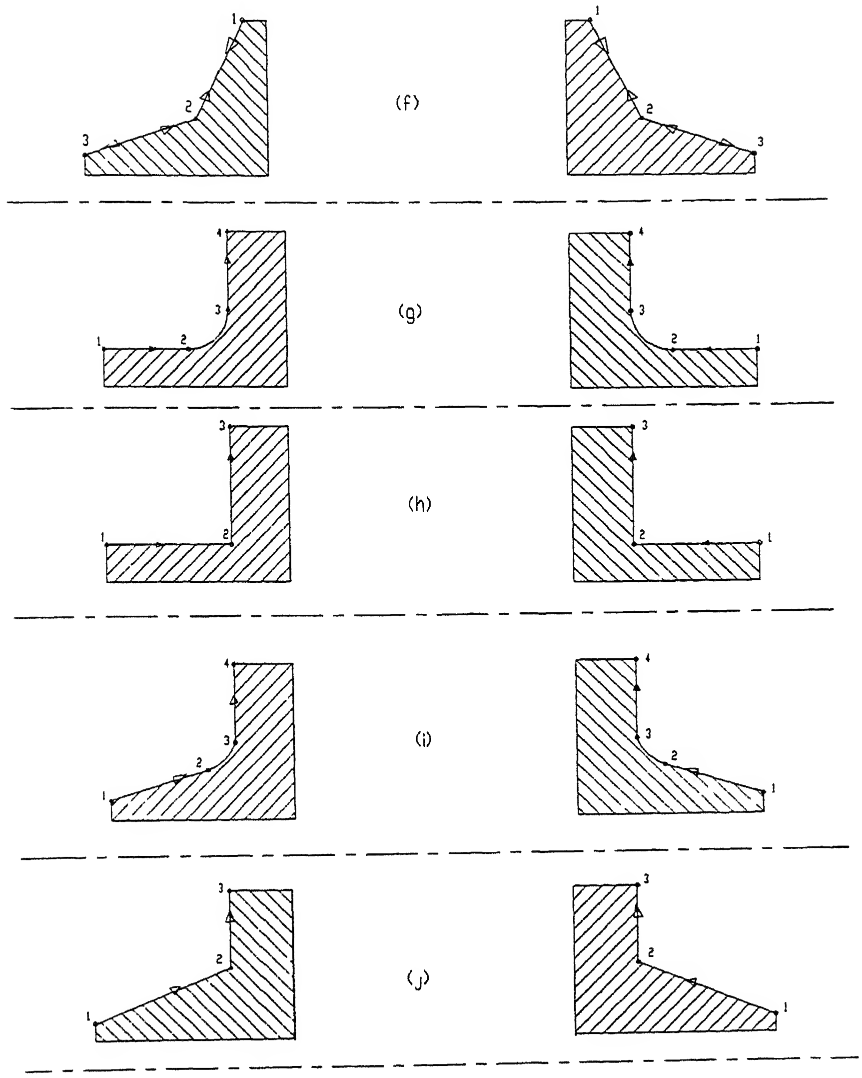


Figure 3.3: Different STEP geometries (continued).

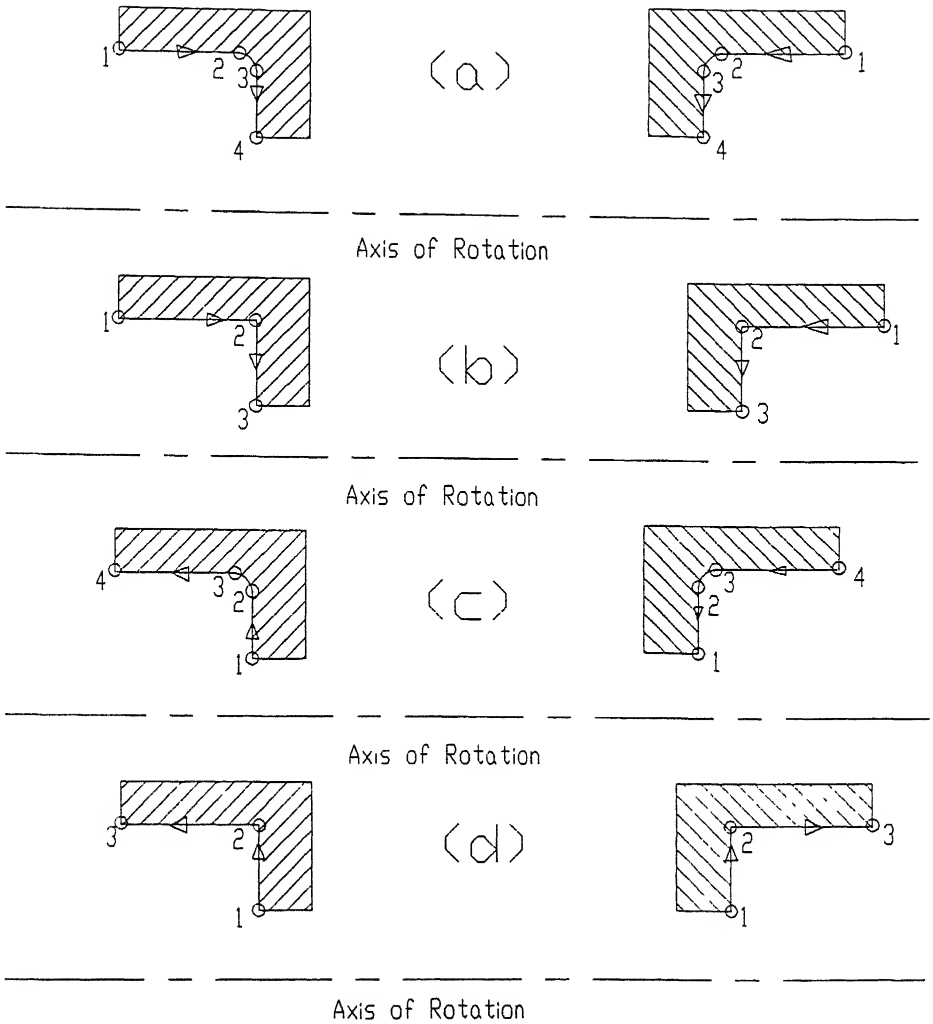


Figure 3.4: Different COUNTER BORE geometries.

if $E_j$ and $E_{j+2}$ are ARCS AND

if included angles of $E_j$ and $E_{j+2} \not> 90^o$,

if PMC of centre points of $E_j$ and $E_{j+2}$ with SS polyarc $\neq$ IN,

if $E_{j+1}$ is VERTICAL LINE,

then MACHINE RECESS on FACE. (See Figure 3.5(a).)

else if $E_{j+1}$ is INTERNAL HORIZONTAL LINE,

then MACHINE RECESS on BORE. (See Figure 3.5(b).)

else $E_{j+1}$ is EXTERNAL HORIZONTAL LINE ,

then MACHINE RECESS on O.D. (See Figure 3.5(c).)

### 3.2.5 J-BEVEL Identification

This is a term that appers to be specific only to TGS, Jamshedpur. It should only be identified after detection the Recess geometries. Figure 3.6(a) and Figure 3.6(b) represent the two different J-Bevel geometries.

if $E_j$ is INCLINED LINE AND $E_{j+1}$ is ARC,

if included angle of $E_{j+1} < 90^o$,

if $Y_1 > Y_2$ AND $Y_2 > Y_3$,

if PMC of centre point of $E_{j+1}$ with SS polyarc $\neq$ IN,

then MACHINE J-BEVEL. (See Figure 3.6(a).)

if $E_j$ is ARC AND $E_{j+1}$ is INCLINED LINE,

if included angle of $E_j < 90^o$,

if ($Y_1 < Y_2$ AND $Y_2 < Y_3$),

if PMC of centre point of $E_j$ with SS polyarc $\neq$ IN,

MACHINE J-BEVEL. (See Figure 3.6(b).)

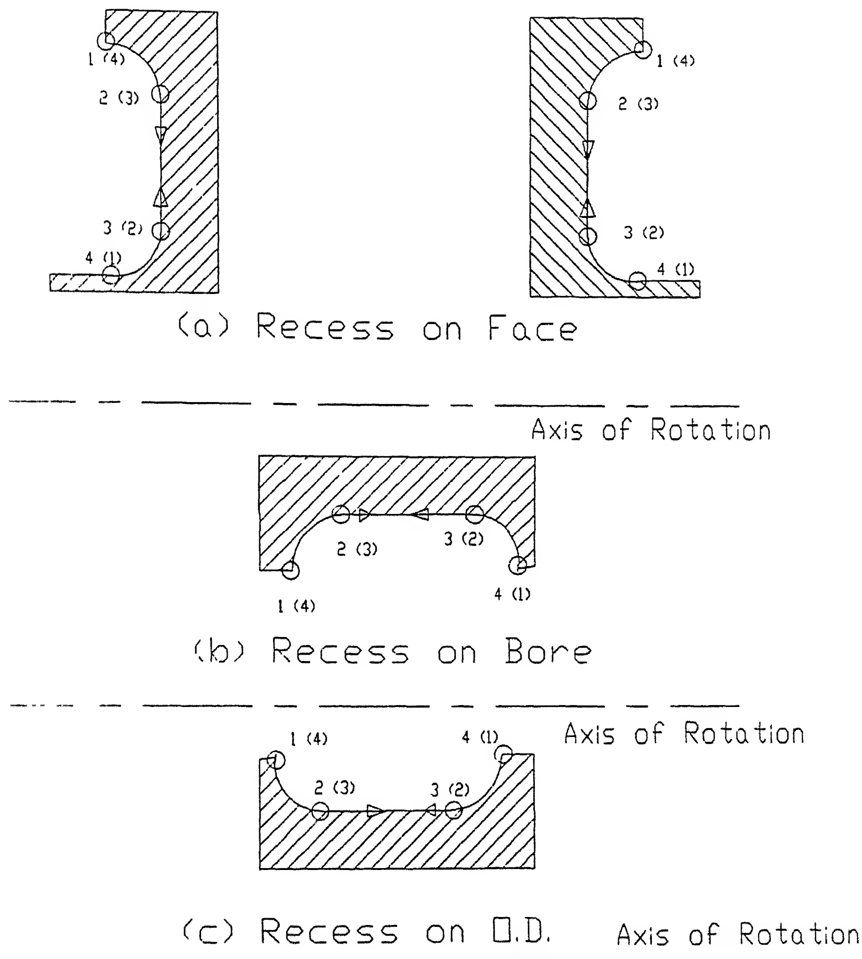


Figure 3.5: Different RECESS geometries.

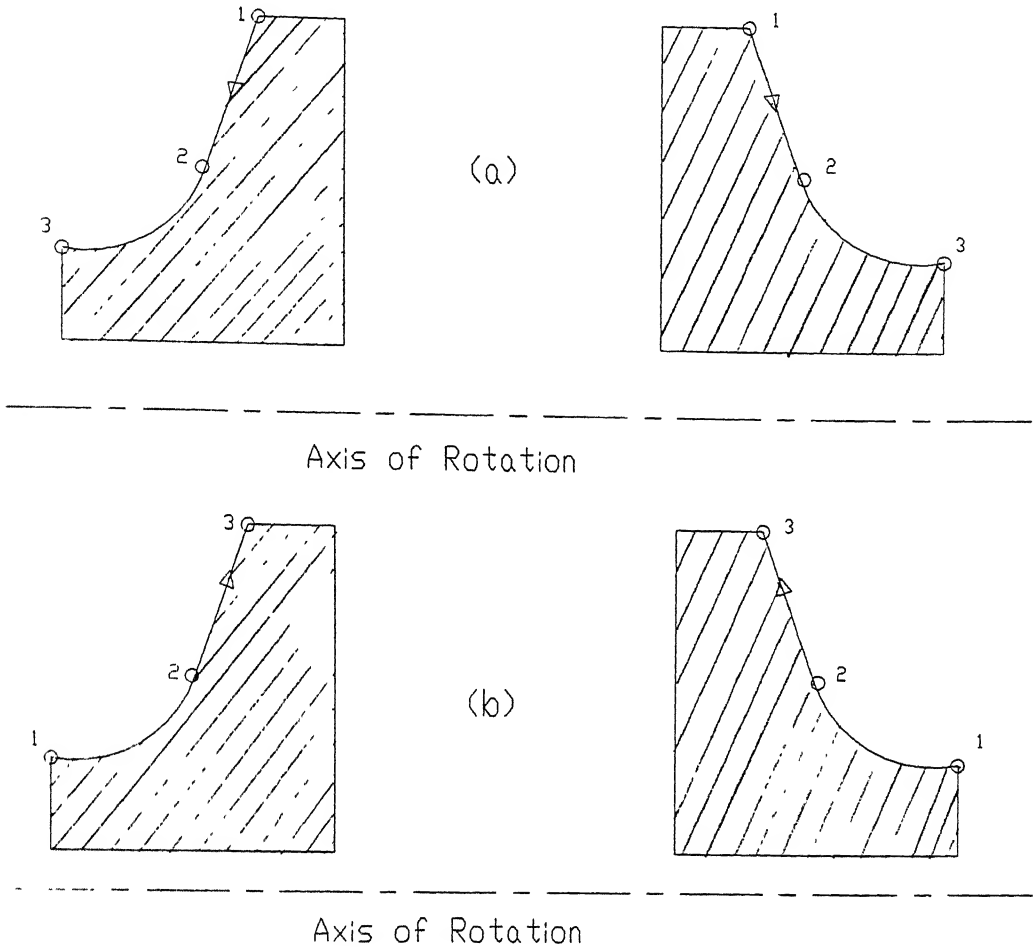


Figure 3.6: Different J-BEVEL geometries.

## 3.3 Sub-Operations Identification Results

Table 3.3 presents the identified attributes and associated machining sub-operation details for Example 1 (Half Casing) shown in Figure 2.5 based on the lists of surfaces accessible from diffrernt tool access directions used for visibility check. It reveals that attributes associated with the surface or group of surfaces, which are visible from more than directions have been repeated and at this stage no attempt is made to select only one direction for machining purposes. But, sequencing should select only one direction for machining of an attribute. At the same time, these heuristics

are necessarily incomplete and will require contant maintenance by the user as his needs become more specific. In the long run, a robust solution will be possible only when Process Planning of level 2 and level 3 are integrated with the current system, alongwith Machine tool, Cutting tool and other databses.

## 3.4 Machining Operations Sequencing

Machining operations sequencing is a very significant and crucial part of operation and process planning, as it considerably influences the total machining time and cost of the product and CNC or NC cutter path generation. It is also the most difficult task as there are no global and standard heuristics or thumb rules which can generate the optimum sequence of the machining operations for the wide range of the components over a wide span of time. At best, Machining operations sequencing heuristics are an incomplete record of the current manufacturing practices being currently used in a particular industry for a certain range of components. These heuristics are quite flexible and may vary according to :

- Functional and design requirements of the component to be manufactured,
- Volume, accuracy and size of the component to be manufactured,
- Type of available machine tools and manufacturing technology : Manual, automatic or CNC-NC,
- Type of of production system : Mass, batch or job-shop production,
- Type of optimizing function : for minimum production time or minimum production cost,
- Availability of specific profile/form cutter and other tools,
- Fixturing setups used.

Table 3.1: Identified machining subopertions for the Example 1.

| AXIALLY FORWARD (0°) accessible surfaces | | |
|---|---|---|
| Entity No. | Attribute name | Machining operation details |
| 1 | Face | Facing |
| 2 | Maximum external dia. | Turn O.D. |
| 9 and 13 | Minimum internal dia. | Drill / Bore |
| 17 | Horizontal line | |
| 18 | Vertical line | |
| 19 | Horizontal line | |
| 20 | Vertical line | |
| 21 | Horizontal line | |

| Surfaces accessible from Axis of Rotation (90°) | | |
|---|---|---|
| 1 | Face | Facing |
| 8 | Face | Facing |
| 9 | Minimum internal Dia. | Drill / Bore |
| 10, 11 and 12 | Internal Flat V-Groove | Machine Flat V-Groove |
| 13 | Minimum internal Dia. | Drill / Bore |
| 14, 15 and 16 | Internal SQUARE Groove | Machine SQ-Groove |
| 17 | Internal horizontal line | |
| 18 and 19 | Internal STEP | Counter Bore |
| 20 and 21 | Internal STEP | Counter Bore |

| AXIALLY BACKWARD (180°) accessible surfaces | | |
|---|---|---|
| 2 | Maximum external dia. | Turn O.D. |
| 3 | Inclined line | Put Chamfer |
| 4, 5 and 6 | External STEP | Step Turn; Shoulder Face |
| 7 | Inclined line | Put Chamfer |
| 8 | Facing | Face |
| 9 and 13 | Minimum internal Dia. | Drill / Bore |

| Surfaces accessible from Outside (270°) | | |
|---|---|---|
| 1 | Face | Facing |
| 2 | Maximum external dia. | Turn O.D. |
| 3 | Inclined line | Put Chamfer |
| 4, 5 and 6 | External STEP | Step Turn; Shoulder Face |
| 7 | Inclined line | Put Chamfer |
| 8 | Face | Facing |

Thus without detailed knowledge of these process planning parameters, it is impossible to generate the optimum sequence in any meaningful manner. Following machining operations sequencing heuristics have been formulated and used in the present work to generate the machining operations sequence for the axisymmetric components from the results of visibility check. These heuristics may be taken extremely general and as a "nominal" sequence which should be edited by the user.

### 3.4.1 Machining Operations Sequencing Heuristics

**RULE 1 :** The component should be held to provide the MAXIMUM VISIBILITY, i.e. out of the axially forward and axially backward directions the axisymmetric component should be held from that direction which has less number of visible surfaces. If both these directions have equal number of accessible surfaces, the component can be held from either side and there may be two different possible machining operations sequences.

**RULE 2 :** FACING should be the first machining operation.

**RULE 3 :** If any surface(s) other than axis of rotation of sweep section and the end faces of the sweep section is(are) visible from Axis of Rotation (90°), then the machining operations for these internal surface(s) should sequenced first starting from minimum internal diameter followed by sequencing for external surface(s) starting from maximum external diameter and using the RULE 4, RULE 5 and RULE 6.

**RULE 4 :** The component should be turned (for external surfaces) or Drilled (for internal surfaces) upto the maximum external diameter or minimum internal diameter. Find minimum and maximum abscissa at the Turned or Drilled dia and assign to $X_1$ and $X_2$ respectively. If more than one segment is present at the maximum external or minimum internal diameter, then adjust the $X_1$ and $X_2$ accoordingly i.e. minimum and maximum abscissa among these segments values should be assigned to $X_1$ and $X_2$ respectively, Refer Figure 3.7.

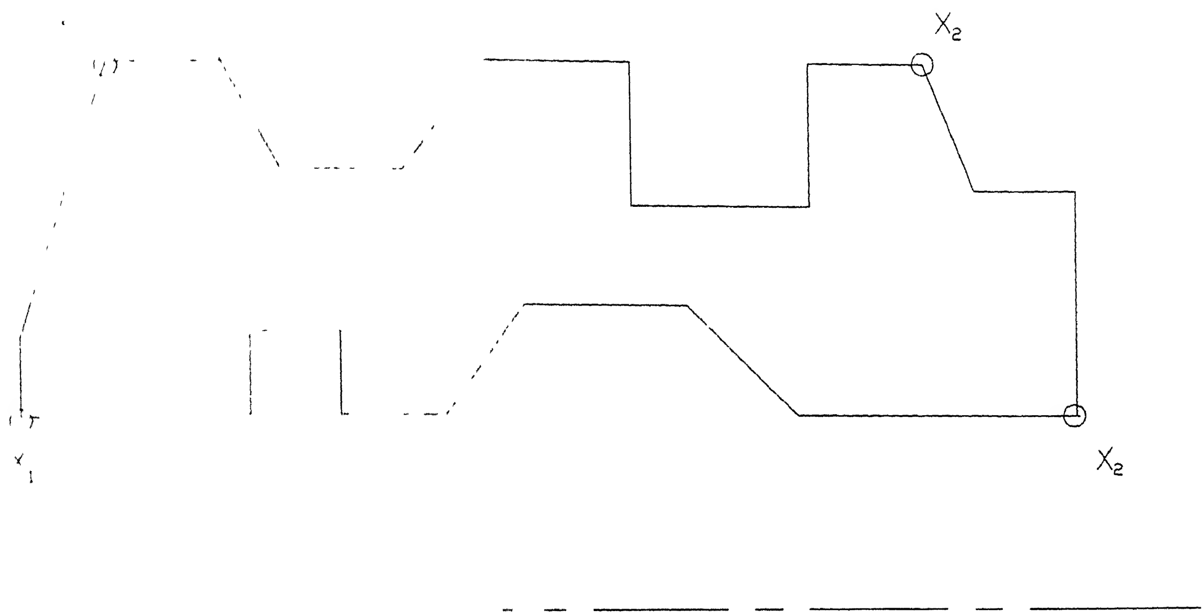


Figure 3.7: Adjustment of $X_1$ and $X_2$ according to RULE 4 of sequencing.

**RULE 5 :** If the component is held from axially backward direction (180°), all entitties having abscissa $\ngtr X_2$ i.e. having abscissa less than or equal to $X_2$ should be machined.

If the component is held from axially forward direction (0°), all entitties having abscissa $\nless X_1$ i.e. having abscissa greater than or equal to $X_1$ should be machined.

**RULE 6 :** If any compound attribute is there it should be machined first else go to NEXT material limit i.e. second maximum external or second minimum internal diameter, and continue till the machining operations for all the surfaces or attributes are sequenced.

Even after these heuristics, many more decisions need to be made without further further details, the "nominal" process plan presented here merely selects the suboperations as listed in the sub-operation list.

## 3.5 Operations Sequencing Results

Based on the machining operations sequencing heuristics the sequenced finish machining operations i.e. operation required to manufacture the the part from intermediate blank, for the Example 1 shown in Figure 2.5 have been presented in the Table 3.5. The component is assumed being held from axially forward direction ($0^0$) in generating the this machining operations sequence. This machining operations sequence is one of the possible sequences and may not constitute the optimum machining operations sequence.

Table 3.2: Sequenced machining opertions for the Example 1.

| Opn no. | Sequenced Machining Operations |
|---|---|
| | Finish Machining :<br>Face; Drill / Bore; Form Flat V-groove;<br>Turn O.D.; Step Turn; Shoulder Face;<br>Remove Sharp Corners.<br>Reverse :<br>Face to Length; Counter Bore; Counter Bore;<br>Counter Bore; Form SQ-Groove;<br>Turn O.D. Complete; Remove Sharp Corners. |

# Chapter 4

# User Interfaces and Results

The interactiveness and user friendliness of any automated or computerized system are primarily dependent on the interfaces the system has with the user. These interfaces are : Input Inerface and Output Interface. Both the interfaces should provide enough guidance and interactiveness, so that even a less skilled user does not find it very difficult and cumbersome to use use and communucate with the system In fact, the system itself should communicate about its requirements, capabilities and applications to the user. These characteristics are highly desirable in an "Intelligent Assistant".

## 4.1 Input Interface and Pre-processing

The degree of integration at the front end of a Computer Integrated Manufacturing environment achieved through the CAPP is determined by the type of input to the CAPP system. To achieve the higher degree of integration at the front end of CIMS, the analytical and planning involvement of the user should be minimized.

The two types of input, which are commonly used for CAPP systems are : (a) User Interactive input through a comprehensive dialogue between the user and the system or (b) Description supplied by any CAD system.

The systems like ICAPP [4], MicroCAPP [5], PRICAPP [10], XPLAN-R [15], TOJICAP [16], the system by Mazumdar [8] and many other systems gather the input INTERACTIVELY from the user through a comprehensive interaction between the user and and the system. But this type of input obstacles in achieving the higher level

of integration at the front end of the CAPP system.

Literature reveals that the most of reported CAPP systems like XPLANE [3] and others, use as their input the solid model of the component. Such models represent only the purely geometric aspects of design information and are informationally more complete than other types other types of geometric representations. But, at present majority of the designs are represented in the form of 2D drawings, drafted manually or by the use of a CAD system . Many designs also exist as 3D wireframe models and less frequently as solid models. So, some authors like Meeran, S. and Pratt, M.J. feel that the needs of today have largely been neglected.

Literature also reveals that some other types of input such as, manufacturing feature based part description by Korde, U.P. *et al.* [6] and primitive vector symbols by Liu, Y.S. and Allen, R. in SIPPS [7] have also been used. But these types of input also necessitate analytical and planning involvement of the user and require the user to be an expertise in manufacturing knowledge.

### 4.1.1 Input Used in the Present Work

In the present work the DXF files of Sweep Sections of the raw stock, intermediate blank and fininshed part, generated using the AutoCAD, have been used as input. For axisymmetric or symmetrical rotational components one-view drawing in a 2D space is sufficient to geometrically represent such a part [14]. The Sweep Section of such types of components can be represented as polyarc consisting only lines and arcs as primitive entities. These DXF files are post processed to extract the geometric information useful in the subsequent Visibility Checking and functioning of the system and to discard the less useful information. If entities like Ellipse, Spline curves or Polyline (specific to AutoCAD) other than lines and arcs have been used in generating the Sweep Section's AutoCAD drawing, then these entities are also converted into lines and/or arcs by the Input Interface of the system.

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**Input Requirements of the Present Work**

Following requirements of the system should be fullfilled while making the AutoCAD drawing of the Sweep Sections :

- The drawing should be drawn to the scale since, presently, the system does not have the capability to handle the scaling and dimensioning of the drawing.
- Absolute zero point (0.0, 0.0) should be used as reference point i.e. lower-left corner of the drawing.
- All CENTRE LINES should be drawn in a seperate layer named as "CENTER".
- All the dimensions should be drawn in the a seperate layer named as "DIM". Although these are currently not being used, it is envisaged that they may be used to relax the first condition above.

### 4.1.2 Why DXF file as input ?

The DXF (Data Interchange File) format is a *neutral file format* i.e. it does not depend on any specific CAD system. Some other *neutral file formats* are IGES (Intial Graphics Exchange Standards) and STEP. These file formats have been defined to permit the transfer of product data between different CAD systems. The formats themselves are intended to be independent of the manner in which the information is stored internally within any particular CAD system . DXF was orginally devised specifically for use with AutoCAD. Unlike IGES, an ANSI standard, and STEP, a forthcoming international standard, DXF is only a *de facto* standard through its wide use as a transfer format, particularly between PC-based CAD systems in general (Meeran, S. and Pratt, M.J. [9]).

## 4.2 Output Interface

The most commoly generated outputs of the CAPP systems include : Graphic Simulation of machining operations sequqnce or File output of Route Card, Process Plan,

Instruction Sheet or NC / CNC-Code, as case may be. Sometimes the generated CNC or NC part program may be loadad to the corresponding machine tool through a computer interface to achieve higher level integration at the rear end of integrated manufacturing environment.

### 4.2.1 Output Generated in the Present Work

In present work, the developed system generates the both types of above mentioned outputs First, the system graphically simulates the results of the Input Interface and pre-processing and Visibility Checking finally, the results of Machining Operations Sequencing are written into an output file in the form of a standard Route Card specific to TGS, Jamshedpur. The Input Interface of the system graphically represents the superimposed sweep sections of finished part and raw material and difference of these two as the machining volume (refer Section 2.1) depicting pictorially what amount of material is to be removed and where. One of these results has been presented in the Figure 2.1. The results of Visibility Checking have been presented in the Section 2.5 and Section 4.3. The results of machining operations identification and sequencing have been presented in the Section 3.3 and Section 3.5 respectively. Finally, sample route card generated by the system and specific to TGS, Adityapur Complex, has been presented in the Table 4.2.1.

## 4.3 More Test Examples

Results of the visibility checking for two more examples have been presented in the following figures.

Figure 4.1 shows the input FPSS polyarc of Example 2, while Figure 4.2(a), Figure 4.2(b), Figure 4.2(c) and Figure 4.2(d) illustrate the surfaces visible from different *Tool Access Directions* commonly used for Turning operations thus decomposing the FPSS polyarc through the visibility checking.

As shown in the Figure 4.2(a), the arc marked as $A$ has Single Tangency Case in the axially forward direction and only portion of the arc between $90^o$ to $180^o$ is visible

Table 4.1: Standard Route Card format generated by the system for TGS, Jamshedpur.

Form No.

TISCO GROWTH SHOP, Adityapur Complex

Master Route Card

Planner:
Project: RC No.:
Part/Sub-assy: Weight: Drawing:
Matl Spec: Matl Code: Qty: Assly:
Sketch

| Opn | Description of Operation | W C | M/C | SMM | Qty | Remarks |
|---|---|---|---|---|---|---|
| | | | | | | |

DELIVER TO :

Prepared By:
Date:

Inspected By :
Date :

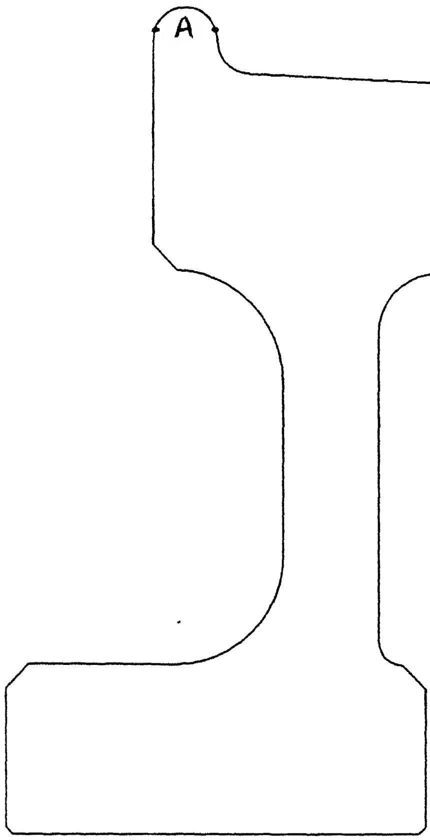


Figure 4.1: FPSS polyarc of the Example 2 (Wheel) as input to the visibility check.

from this direction so it has been decomposed from $90^o$ to $180^o$ as visible part from axially forward direction and as shown in the Figure 4.2(c), the same arc also has Single Tangency Case in the axially backward direction and only portion of the arc between $0^o$ to $90^o$ is visible from this direction so it has also been decomposed from $0^o$ to $90^o$ as visible part from axially backward direction while, the same arc is *fully* visible from radially inward direction as shown in the Figure 4.2(d).

Figure 4.3 shows the input FPSS polyarc of the Example 3, while Figure 4.4(a), Figure 4.4(b), Figure 4.4(c) and Figure 4.4(d) illustrate the visible surfaces. Many other examples are also handled by the implementation of CARGAC.

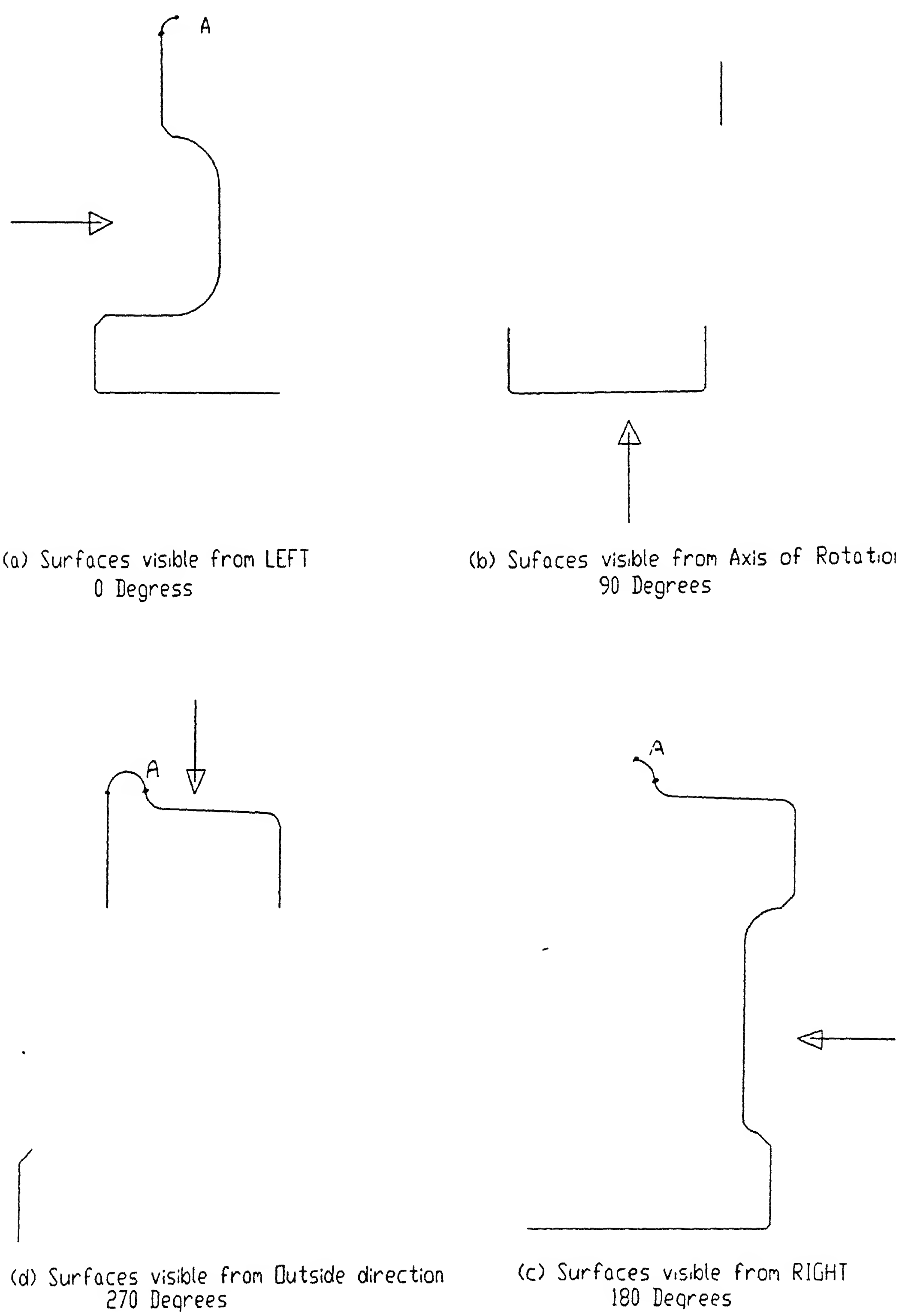


Figure 4.2: Results of visibility check for the Example 2 (Wheel) from different directions.

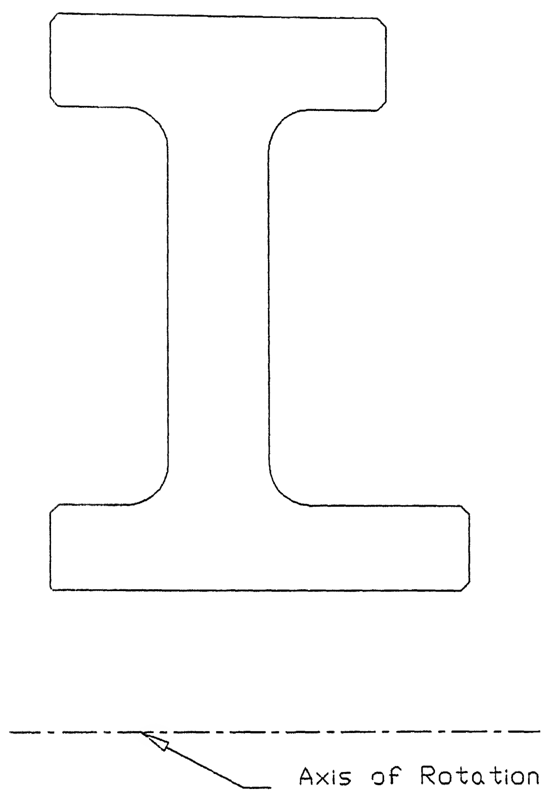


Figure 4.3: FPSS polyarc of the Example 3 (Gear Blank) to the visibility check.

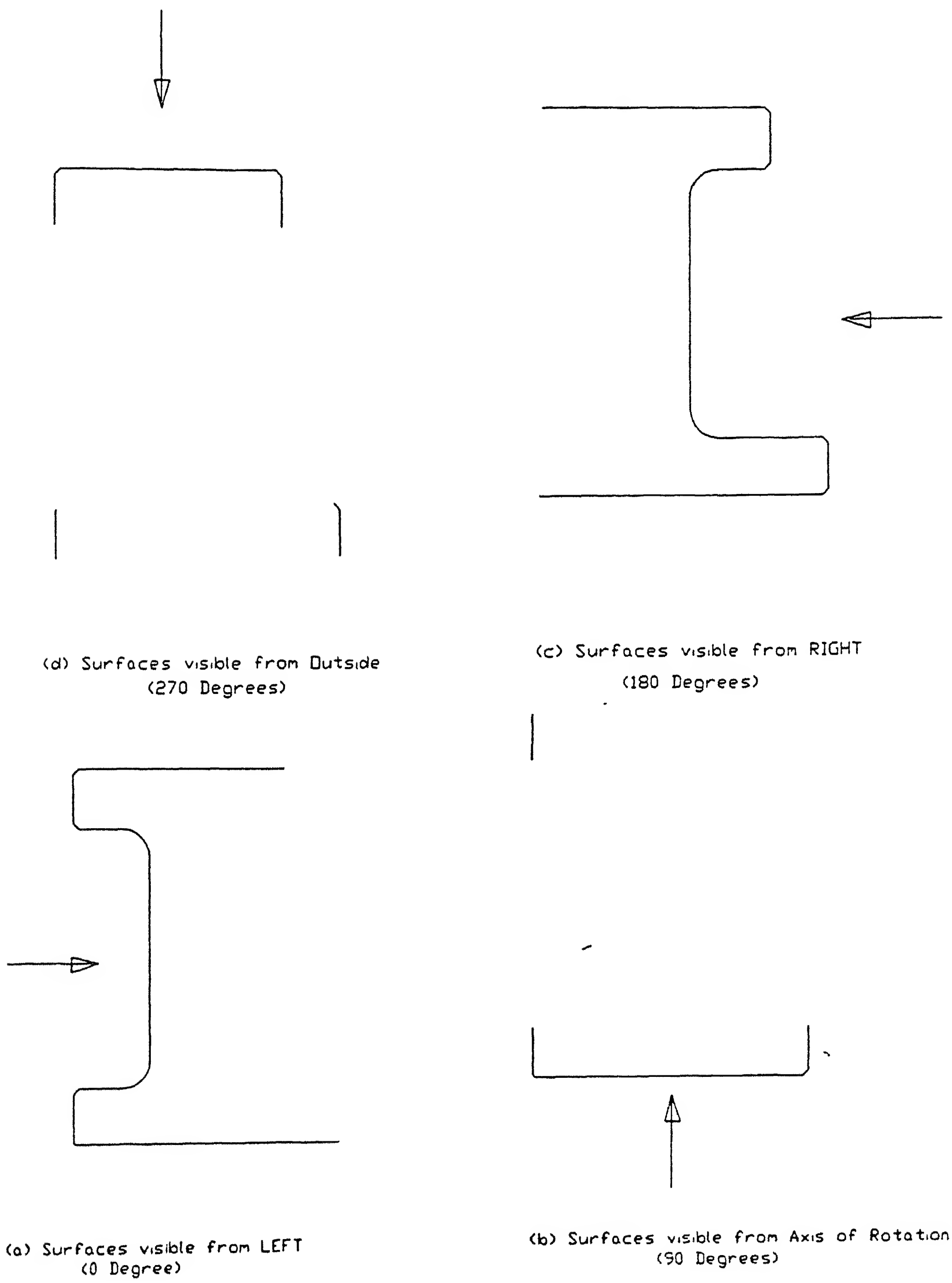


Figure 4.4: Results of visibility check for the Example 3 (Gear Balnk) from different directions.

# Chapter 5

# Conclusion and Extensions

## 5.1 Conclusion

The prime objectives of the present work were :

- To develop the Computer Assisted Operation Planning System having the capability of integrating itself with the any CAD package through the DXF file formats.

- To explore the possibility of using the visibility status of a surface in determining the possible machining direction(s), identifying the simple attributes (compound attributes) associated with a surface (group of surfaces) and associated machining operation and finally sequence these identified machining operations.

The INPUT INERFACE and PRE-PROCESSING of the developed system establishes the first objective successfully. The VISIBILITY CHECK successfully decomposes the a sweep section polyarc into surfaces lists visible from directions of tool access and listing the possible directions from which a surface can be accessed for the machining purpose. The results of Example 1 in Section 2.5, Example 2 and Example 3 in Section 4.3 reveal this. While, the comparision between the Finish Machining operations sequence of the Table 1.1.1 of Section 1.1.1 and Table 3.5 of Section 3.5 reveal that there can be variations between the machining operations sequence being actually used in the industry (TGS, Adityapur) and that of generated by the system. This variation can be attributed to the fact that the success of visibility check

in generating the machining operations sequence and subsequently CNC part program depends on the robustness, comprehensiveness and the generality of machining operation identification and sequencing heuristics.

## 5.2 Future Extensions

In the present work was aimed at level 1 process planning i.e. operation planning of axisymmetric components from the AutoCAD drawing of the components through the use of visibility check but ultimate goal should be to generate the optimum CNC part program from the CAD model of the components to achieve the true integration of CAD with CAM through CAPP thus justifying the very purpose of establishing the CAPP so there is an intense scope of extending the present work in the future with the following objectives :

- Attempts were not made in the present work to optimize the machining operations sequence, in the spirit of an "Intelligent Assistant" and wide variability in the sequencing, we feel that rather than optimizing the sequence, an on-line editor should be provided to allow the user to adjust the machining operations sequence as appropriate. An acceptable machining operations sequence can only be detemined by system only when Process Planning of level 2 and level 3 are carried out. Even then the final control should rest with the user in the spirit of the "Intelligent Assistant" rather than an "Automated Decision Making System".

- Level 2 and level 3 process planning should be attempted by incorporating the necessary data bases of cutting tool material, work material, cutting speed and feed data, etc., in the system to have computer integrated manufacturing environment. We note that a number of commercial software tools for this are already available.

- The same work should be extended for the prismatic parts also.

- The result of visibility checking should be used to generate CNC-code.

- Attempts should also be made to handle the scaling and dimensioning of the engineering drawing in the DXF files.
- Other neutral file formats like IGES, STEP should also be interfaced with the system.

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# APPENDIX A

A DXF file is an ASCII format, with all alphabatical characters in upper case. It consists of FOUR sections namely; HEADER, TABLES; BLOCKS and ENTITIES. The geometric information about entities like LINE, ARC, CIRCLE, POLYLINE, and etc. is presented in both BLOCKS and ENTITIES section. Each information is associated with an integer group code followed a string or float number. Tables A.1, A.2 and A.3 present the DXF formats for LINE, ARC, CIRCLE respectively.

Table A.1: DXF file format for entity LINE.

| Information | Interpretation |
|---|---|
| 0 | Start of entity |
| LINE | Name of an entity |
| 8 | Layer name identifier |
| DWG | entity resides on a layer named as "DWG" |
| 6 | Line type identifier |
| 0 | Solid line |
| 62 | Entity color identifier |
| 3 | Entity color code |
| 10 | Start X |
| 9.5 | Value of start X |
| 20 | Start Y |
| 7.5 | Value of start Y |
| 30 | Start Z |
| 0.0 | Value of start Z |
| 11 | End X |
| 12.45 | Value of end X |
| 21 | End Y |
| 15.60 | Value of end Y |
| 31 | End Z |
| 0.0 | Value of end Z |

Table A.2: DXF file format for entity ARC.

| Information | Interpretation |
|---|---|
| 0 | Start of entity |
| ARC | Name of an entity |
| 8 | Layer name identifier |
| DWG | entity resides on a layer named as "DWG" |
| 6 | Line type identifier |
| 0 | Solid line |
| 62 | Entity color identifier |
| 3 | Entity color code |
| 10 | Center X |
| 9.5 | Value of center X |
| 20 | Center Y |
| 7.5 | Value of center Y |
| 30 | Center Z |
| 0.0 | Value of center Z |
| 40 | Radius identifier |
| 15 | Radius of the arc |
| 50 | Start angle identifier |
| 90 | Value of start angle |
| 51 | End angle identifier |
| 180.0 | Value of end angle |

Table A.3: DXF file format for entity CIRCLE.

| Information | Interpretation |
|---|---|
| 0 | Start of entity |
| CIRCLE | Name of an entity |
| 8 | Layer name identifier |
| DWG | entity resides on a layer named as "DWG" |
| 6 | Line type identifier |
| 0 | Solid line |
| 62 | Entity color identifier |
| 3 | Entity color code |
| 10 | Center X |
| 9.5 | Value of center X |
| 20 | Center Y |
| 7.5 | Value of center Y |
| 30 | Center Z |
| 0.0 | Value of center Z |
| 40 | Radius identifier |
| 20.5 | Value of the radius of the circle |